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The Torresdale Conduit.*

BY JOHN W. HILL,

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The Torresdale Conduit, constituting, as it does, one of the important elements of the great filtration system for the improvement of the water supply of Philadelphia, would, on account of its magnitude alone, command the interest of engineers. It has, however, been made the subject some criticism. In this paper, the author, who was Chief Engineer in charge of its construction, presents, with ample illustrations, a complete history of the work of construction, the subsequent examination, and present condition of the work.—[THE EDITOR.]

The Torresdale Conduit, Contract No. 14, Improvement, Extension and Filtration of the Water Supply of Philadelphia, is a large inverted syphon intended to conduct the filtered water from the clear water basin at Torresdale to the pumping station at Lardner's Point. Its nominal capacity is 300,000,000 gallons per day of twenty-four hours, with a loss of head between

*A paper read before the Engineers' Club of Philadelphia, and repeated by request before the Institute.

end shafts of 8.6 feet, and a mean velocity of flow of 5.276 feet per second.

Influent Shaft No. 1, is located 1,525.5 feet south of the center line of Pennypack street, at the Torresdale Filters, and from this point the conduit proceeds upon city property, under Pennypack Creek, and through the House of Correction grounds to Holmesburg Avenue; thence south on Eugene Street, as laid down on the City plan, to its intersection with Delaware Avenue; thence south on Delaware Avenue to Effluent Shaft No. 11, at Lardner's Point Pumping Station. The nine intermediate working shafts were distributed along the line of work at locations about 1,400 feet apart, making thus the average length of heading about 700 feet.

The depth of Shaft No. 1, at the Torresdale end of the Conduit, measured from the finished head, is 127.39 feet, and of Shaft No. 11, at Lardner's Point, from same point of measurement, 117.05 feet. The length of tunnel between end shafts is 13,809.2 feet, and total length of water flow from the center of influent legs at Shaft No. 1 to the center of effluent legs at Shaft No. 11, about 13,968.5 feet. The diameter of Shaft No. 1 of the tunnel and the lower 68.1 feet of Shaft No. 11 is uniformly ten feet seven inches on the neat lines of brickwork. The upper 48.9 feet of Shaft No. 11 is twenty-one feet one inch diameter.

The general depth of the center line of tunnel is about 100 feet below ground level.

The filtered water is drawn from the clear water basin at Torresdale to Shaft No. 1 through a concrete metal reinforced conduit of horseshoe section, equivalent in area to a circle 10 feet in diameter, 855 feet long from the outlet of the clear water basin to the shaft. This conduit is connected with the shaft at elevation 186.50 T. D. center line, through two cast-iron nozzles bolted to the steel shell of the shaft, one eight feet diameter, and the other seven feet diameter, the direct connection to the conduit being made through the larger nozzle. Each of the nozzles is connected with the conduit and the clear water basin through lengths of riveted steel pipe, twenty-one feet long for the eight foot nozzle, and fourteen feet long for the seven foot nozzle, the steel pipes being enveloped in concrete.

The effluent legs at Shaft No. 11 are respectively fourteen

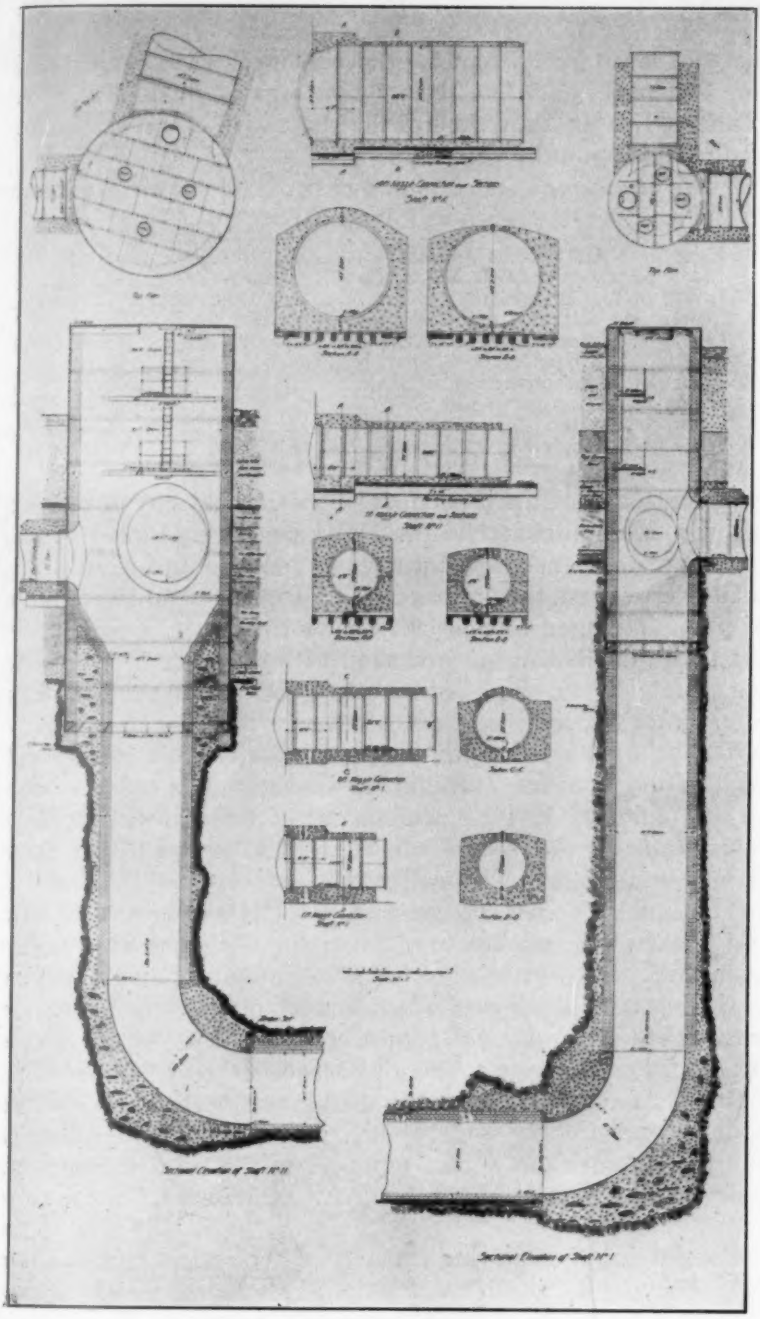

PLATE I.—Typical Sections of Shafts No. 1 and No. 11.

feet and seven feet diameter, of riveted steel, each twenty-eight feet in length, and, like the influent legs at Shaft No. 1, are connected to the steel shell of the shaft with cast-iron nozzles, and rounded mouthpieces.

The elevations of the conduit and connections with reference to Torresdale Datum are as follows:

Head of Shafts Nos. 1 and 11	216.46
Invert of tunnel at Shaft No. 1	89.07
Invert of tunnel at Shaft No. 11	99.41
Center line of tunnel at midlength	99.49
Invert of 8-ft. connection at Shaft No. 1	182.50
Invert of 7-ft. connection at Shaft No. 1	182.50
Invert of 14-ft. connection at Shaft No. 11	178.00
Invert of 7-ft. connection at Shaft No. 11	178.00
Floor clear water basin, Torresdale	192.00
High water line, clear water basin, Torresdale	207.00
Invert of 10-ft. Conduit from C. W. Basin to Shaft No. 1	181.50

[Torresdale Datum is 200 feet below City Datum, or 200 feet below mean high water in the Delaware River, Philadelphia.]

Down to the rock, and for a short distance into it, until the shells were sealed, the permanent and working shafts were made of steel plate lined with brick. Below the rock the permanent shafts are lined with brick backed with concrete. The working shafts were not thus lined, but the rock left in the condition found after blasting.

The bends at the bottom of the shaft are entirely of concrete, built to forms ten feet seven inches diameter, on a radius of center line of fifteen feet nine inches diameter, finished with a granolithic surface one inch thick. The tunnel is lined with hard-burned brick backed with concrete.

The lining of invert is everywhere of two courses of brick, laid to templets on a cradle of concrete. The arch ring varies from three to five courses of brick, depending upon the nature of the material in the roof of the tunnel, above which concrete was packed up to the rock, and where, for lack of space above the arch ring, concrete could not be placed, the voids were filled with Portland cement grout pumped in under about eighty-five pounds pressure per square inch. The grout was usually pumped through the weeper pipes set in the brick masonry to lead the water from back of the arch to the interior of the tunnel or shaft.

Considering the carrying capacity of 300,000,000 gallons per day, the velocity at different points between the clear water

basin at Torresdale and the pump wells at Lardner's Point will be as follows:

	Ft. Per Second
From the clear water basin at Torresdale to Shaft No. 1	5.92
Combined 8-ft. diameter and 7-ft. diameter nozzles at Shaft No. 1	5.163
Shaft No. 1 and tunnel	5.276
Shaft No. 11 at lower end	5.276
Shaft No. 11 at upper end	1.319
Aqueduct to pump wells 2, 3 and 4	3.015
Aqueduct to Lardner's Point Pumping Station No. 1	1.984

The total loss of head between the clear water basin at Torresdale and pump wells at Lardner's Point, when the conduit is delivering 300,000,000 gallons per day, is estimated at 9.25 feet.

To prevent the tunnel from becoming air bound it is graded upwards nine inches per 1,000 feet from Shaft No. 1, Torresdale, to Shaft No. 11, Lardner's Point. Air which may be carried down Shaft No. 1 will either be carried into the tunnel or rise through the water in the shaft. Such air as may be carried into the tunnel will flow with the water and be vented at Shaft No. 11, the upward inclination of the tunnel from the influent to the effluent shaft preventing the accumulation of air, which might be a cause of interference with the operation of a horizontal tunnel. Should there ever be any indications of air sticking, as it were, in the conduit, it is believed that it can readily be removed by increasing the speed of the pumping machinery at Lardner's Point, lowering the level of water temporarily in the pump wells, and creating an increased velocity of flow through the conduit until the air is removed. The conditions under which the water is conducted to the influent shaft, and the upward gradient of the tunnel from the influent to the effluent shafts, are thought to be effectual safeguards against the introduction of any considerable quantity of air into the conduit, or of any reduction of its capacity by the accumulation of air at any point along the roof.

Character of Materials on the Line of Work.

The only deep rock operations from which information could be obtained upon the probable character of the material to be encountered in driving the shafts and headings for the northerly end of the conduit are found near the county prison, north of Pennypack Creek. Here the rock excavation in the deep quarry is very hard, with few seams or fissures, and a small

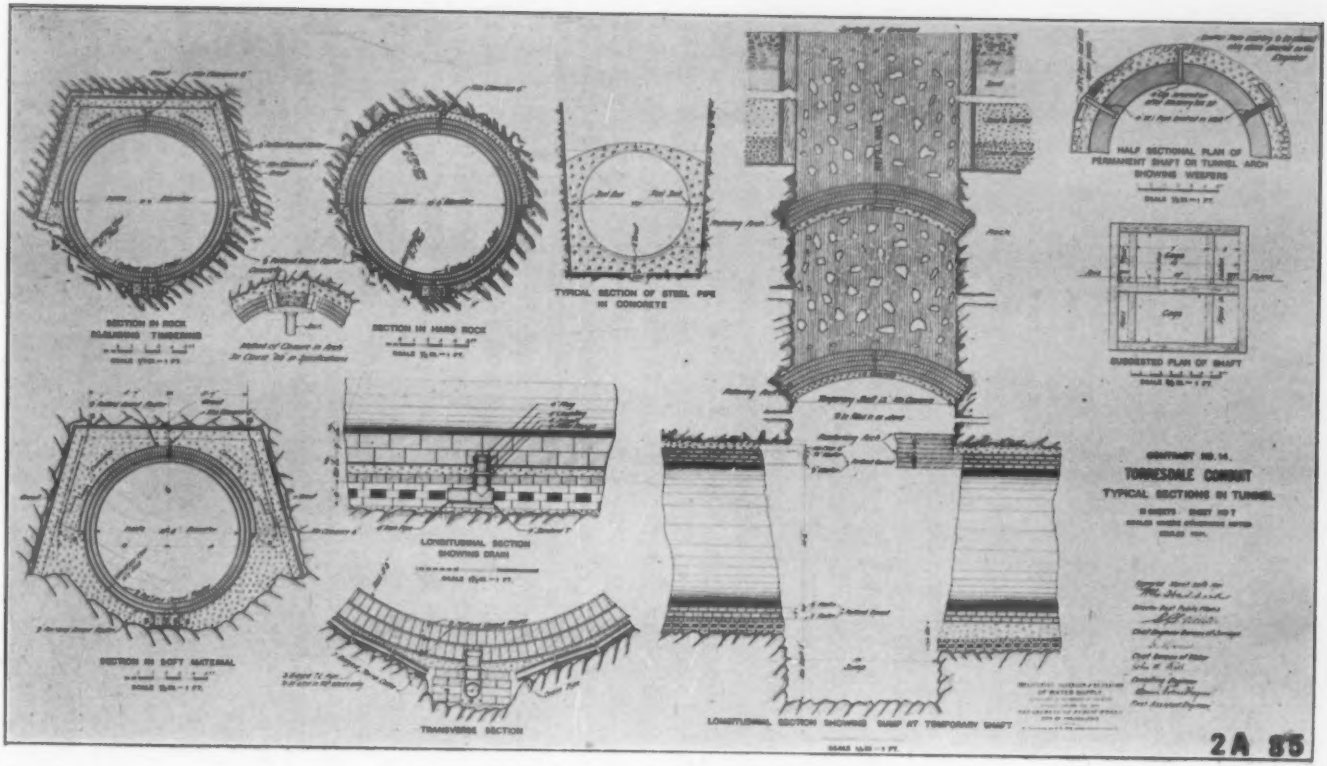
SECTION IN ROCK
SECTION IN HARD ROCK
TYPICAL SECTION OF STEEL PIPE IN CONCRETE
HALF SECTIONAL PLAN OF PERMANENT SHAFT OR TUNNEL ARCH SHOWING WEEPERS
SUGGESTED PLAN OF SHAFT
CONTRACT NO. 14.
TORRESDALE CONDUIT
TYPICAL SECTIONS IN TUNNEL
SECTION IN SOFT MATERIAL
LONGITUDINAL SECTION SHOWING DRAIN
TRANSVERSE SECTION
LONGITUDINAL SECTION SHOWING SUMP AT TEMPORARY SHAFT
2A 85

PLATE II—Typical Sections in Tunnel.

amount of water, and the typical sections showing excavation for the conduit in hard rock were partially based on this information.

The experience with the conduit confirmed the diamond drill borings, which showed that the character of the rock in the quarry is not maintained for the whole length of the work, and that a great change in the hardness and stability of material takes place in going from the north to the south end. The treacherous material, however, is not continuous, but occurs in reaches of the work, sometimes being abreast of and sometimes crossing the line of the tunnel diagonally.

The diamond drill borings which preceded the preparation of the detail plan indicated the varying character of the rock, but the rapidity with which some of the material would deteriorate upon contact with the air in the tunnel was not fully suspected in advance.

Operations on the conduit were conducted from nine working and two permanent (end) shafts. All shafts were lined to the solid rock. The working, as well as the permanent, shafts were constructed with steel shells sunk into hard rock and sealed, the interior being lined with an eighteen ring of hard-burned stretcher brick laid in cement mortar in the permanent shafts, and a nine inch ring in the working shafts. The sinking and lining of the steel shells for the end shafts was much more carefully executed that it was for the working shafts, because the latter, upon completion of the work, were closed with brick arches continuous with the arch of the tunnel, above which were constructed in each shaft two relieving arches to take a part of the weight of the backfill of the shaft off the arch of the conduit. From the arch of the conduit to ground level the working shafts were solidly backfilled with selected materials.

About ninety-one per cent. of the entire tunnel excavation was in hornblendic and biotite gneiss rock, which required no timber to support the roof. In the north end the rock was very good, but the flow of water, as will be noticed later, was large enough to render it a matter of concern to the contractor and interfered with the lining of the tunnel. Between Shafts Nos. 4 and 7, the rock was of excellent quality, and the flow of water not enough to hinder the work.

Between Shafts Nos. 8 and 9, and in the north heading of

PLATE II.—Typical Sections in Tunnel.

Shaft No. 8, the micacous rock was very rotten and treacherous, and required heavy and close timbering to prevent dangerous falls. In all such localities the thickness of the arch was increased to four or five rings of brickwork.

Excepting where falls in the roof occurred, the rough diameter of the excavation, heading and bench, is about fourteen feet.

For several hundred feet in the north heading of Shaft No. 9, under the Disston Saw Works, the collar beams and posts supporting the roof abut against each other to prevent dangerous falls and possible injury to valuable surface structures. The placing of this timber not only delayed the progress of the excavation, but naturally occasioned great loss of time in its removal in part, and in placing the brick arch and the concrete packing above and around it.

In carrying forward the arch, for nearly sixty per cent. of the total length enough water was encountered dripping from the rock to make it almost impossible to insure proper setting of the mortar joints excepting the water was wholly excluded from the back of the brickwork, and in order to prevent this, wherever wet roof was met, tar paper in two layers from springing line to springing line of the arch was used to exclude the water until the mortar had set. It was not thought that the tar paper would be a permanent protection in this respect, but experience demonstrated that it could be relied upon to exclude the water for many days, during which time the mortar in the brickwork had sufficient time to harden.

In strengthening Shaft No. 7 as originally sunk and lined, while the contractor insisted that it was perfectly secure for his work, it was not thought that it was entirely safe, either for the contractor's men or for the employees of the City, and in order to guard against any risk from inflows of water from the Delaware River, which, aside from the possible accidents to men employed in the shaft or in the headings driven, would have occasioned a very serious delay in recovering the shaft or in driving a new one, it was decided to reinforce with a ring of concrete from twelve to eighteen inches thick, a portion of the shaft, beginning eleven feet above the shoe of the steel shell, and continuing down thirty-eight feet six inches into the excavated rock.

PLATE III.—Cast Iron Shoe and Section of Steel Shell in Temporary Shafts

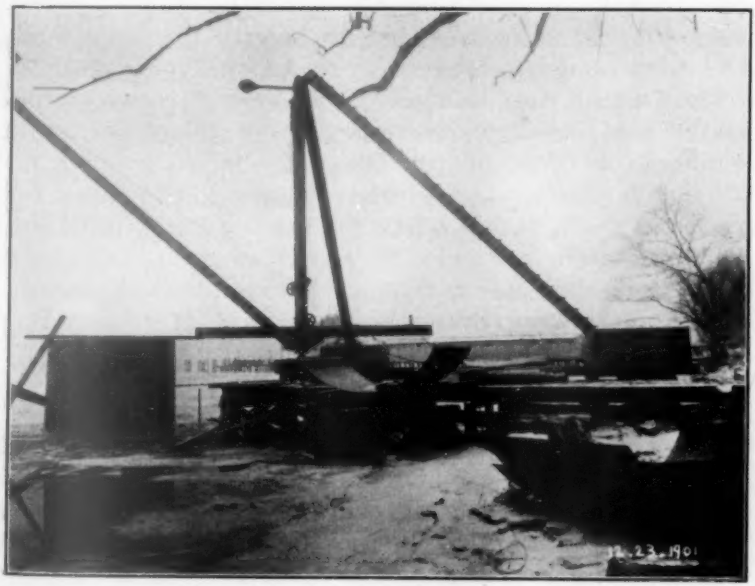

PLATE IV.—Head of Steel Shell, Shaft No. 7.

In the original plans for the work it was thought that the bends at the ends of Shafts Nos. 1 and 11 could be turned of brick, but study of the matter during progress of lining the tunnel led to the belief that these bends would be smoother and more uniform in section, and more stable, if constructed of concrete than if the attempt was made to line them with brick. Forms were then built, bolted, and doweled together, and carefully tested for dimensions at the surface of the ground, and then taken apart and set up in their true positions at the bottom of the shafts, around which was placed concrete entirely filling the spaces between the forms and the ragged rock around the excavation.

Air Compressors, etc.

Compressed air for the different sections of the work was furnished as follows:

Section 1: Shafts Nos. 1, 2, 3 and 4, by a Rand single stage compressor, with twenty-four inch air cylinder, twenty-four inch steam cylinder, thirty inch stroke, running at eighty-three revolutions per minute, located at Shaft No. 3, on the House of Correction grounds.

Section 2: Shafts 5 and 6, by two Ingersoll-Sergeant single stage compressors, with twenty-two and one-quarter inch air cylinders, twenty-two inch steam cylinders, twenty-four inch stroke, running at ninety-four revolutions per minute, located at the intersection of Eugene and Bleigh Streets.

Section 3: Shafts 7 and 8, by one Sullivan compound, or two stage compressor, with fourteen inch and twenty-two inch air cylinders, fourteen inch and twenty-two inch steam cylinders, all twenty-four inch stroke, running at 110 revolutions per minute. Located in the Pennsylvania Railroad yard at the foot of Disston Street, Tacony.

Section 4: Shafts Nos. 9, 10 and 11, by one Rand duplex compressor, with twenty inch air cylinder, twenty inch steam cylinder, thirty inch stroke, running at eighty-seven revolutions per minute; and one Ingersoll-Sergeant single stage compressor, with twelve inch air cylinder, twelve and one-quarter inch steam cylinder, and fourteen inch stroke, running at 155 revolutions per minute. Located at the intersection of Delaware Avenue and Levick Street.

The free air capacity provided for the different sections was as follows:

Section 1,	2,670	cubic feet	per minute.
" 2,	960	"	"
" 3,	1,160	"	"
" 4	2,185	"	"

Steam was supplied to the machine from locomotive and return tubular boilers, working at pressures ranging from ninety to one hundred pounds by gauge, and compressed air was used at from seventy to eighty pounds pressure by gauge.

Head houses were built over each shaft, excepting Shaft No. 11, where the elevation of muck and lowering of men and materials, was done by a swinging boom derrick and dumping buckets. All head houses were provided with cages fitted with safety catches, upon which narrow-gauge dump cars were run for raising muck and lowering materials.

All rock drills and some of the pumps were operated by compressed air, the exhaust from which served to ventilate the headings and shafts.

Meeting of Headings.

In the following table are given the dates of meeting of headings, errors of line, errors of grade, and horizontal distance between shafts from which the operations were conducted.

Plumb-bobs and a Buff and Berger plunging transit both were used to project the line of the work from the surface of the ground to the bottom of the shaft. The large error of line at the meeting of the headings between shafts Nos. 5 and 6, is due to the use on this section of the transit only in projecting the surface line down Shaft No. 5.

The error of line in the meeting of Shafts Nos. 3 and 4 was due to the same cause, Shaft No. 3 being too much out of plumb to admit of using the plumb-bob.

Between Shafts	Date	Time	Error in Line. Inches	Error in Grade. Feet	Distance between Shafts. Feet
Nos. 1-2	July 21,'03,	6.00 P.M.	5-¼	.007	1351
" 2-3	April 12,'03,	7.00 A.M.	⅝	.0312	1330
" 3-4	Feb. 7,'03,	5.30 P.M.	4	.0208	1244
" 4-5	April 27,'03,	7.00 P.M.	½	.004	1640
" 5-6	Nov. 9,'02,	4.00 A.M.	7	.0104	1353
" 6-7	May 23,'03,	3.00 A.M.	1-½	.020	1562
" 7-8	May 13,'03,	6.00 P.M.	⅛	.013	1635
" 8-9	June 6,'03,	12.00 M.	¾	.014	1580
" 9-10	Oct. 11,'02,	2.15 P.M.	¼	.0104	1110
" 10-11	Dec. 13,'02,	2.00 P.M.	1-¾	.0312	1003

PLATE V.—Sinking Steel Shell, Shaft No. 9.

PLATE VI.—Diaphgram for Air Lock, Shaft No. 2.

HISTORY OF THE CONTRACT.

The history of the contract is shown in the following table, including the assumed date of completion:

Date of letting	May 28, 1901.
Date of award	August 28, 1901.
Date of contract	October 4, 1901.
Date of revision of paragraphs 24 and 30 of the specifications	October 21, 1901.
Time limit for completion of work	Nine (9) months.
Notice to begin work	January 9, 1902.
Expiration of contract time	October 9, 1902.
Date of completion	April 23, 1904.
Default in time of completion	424 working days.

There was at no time any indication of lack of energy on the part of the contractor to forward the work to the earliest possible completion. From its inception, about December 1st, 1901, to April 23rd, 1904, at no time was the work even temporarily abandoned, although certain of the shafts, like Shaft No. 4 and Shaft No. 7, were, for reasons hereafter to be explained, abandoned for short lengths of time.

The first cause of delay was due to the decision of the City to deepen all shafts by ten feet, which conclusion was reached March 25, 1902, after Shaft No. 9 had been driven to the line of the tunnel. The terms of the contract provided that the first Shaft (No. 9), which seemed to show from the diamond drill borings the poorest material in the rock, should be driven in advance of the other shafts to the line of the tunnel, in order to determine whether the center line, as shown by the original plans, could be safely adopted for the prosecution of the work. Upon sinking this shaft to the elevation originally shown, the material was found to be of such treacherous character that it was determined to lower the center line of the tunnel everywhere by ten feet. Although several of the other shafts were in progress simultaneously with Shaft No. 9, they were not advanced as rapidly as this shaft for the reason given.

In the construction of Shaft No. 7, in Eugene Street, between Cottman and Princeton Streets, and about opposite St. Vincent's Orphan Asylum, when the steel shell reached the rock, and the work of driving into the rock was begun, it was regarded as unsafe for use, and work was temporarily suspended upon orders of the City, until such time as the shaft might be made

safe for the use of the Engineers and Inspectors, as well as the men in the employ of the contractor. Nearly one month's time was lost between the date when the work was suspended and the operations again resumed.

In carrying forward the north heading from Shaft No. 9, a soft seam, consisting apparently of a mixture of plastic clay and rotten, micaceous rock, was encountered, requiring very careful and constant timbering of the work as the heading advanced. From November 6th to December 26th, 1902, the rate of progress was less than twelve inches per day. From January 1st to February 5th, 1903, the rate of progress represented less than twelve inches a day; the normal rate of progress throughout the work was slightly over two feet per day.

On February 5th, 1902, owing to an accident, Shaft No. 4 was so seriously damaged that notwithstanding vigorous efforts were made to reclaim it, it was finally abandoned on March 17th, 1902, at a depth of about fifty feet below ground level. The second shaft was then located about 100 feet south of original Shaft No. 4, and driven down to the line of the tunnel without any further trouble at this station.

Owing to the inflow of water, an attempt was made to use an air lock on Shaft No. 2, but after trial of about six weeks, this was removed, and progress continued to the end of the work in the open shaft and headings.

During the coal strike in 1902, serious difficulty was encountered in securing enough coal to keep the machinery running at all the shafts, and especially between Shafts Nos. 1 and 8 there were times when the supply of fuel was so low as to prevent the working of the usual double shift of men. In due time this trouble was remedied through the kindly aid of the officials of the Pennsylvania Railroad.

Considering the very large amount of brick required for lining the permanent shafts and tunnel (over 9,700,000) considerable difficulty was experienced in getting brick of a satisfactory quality. Several cargoes of brick were offered for use and rejected entirely by reason of the very large percentage found unsuitable upon inspection, and the contractor was, therefore, directed to procure bricks from manufacturers whose general run of material met the requirements of "sound, straight, hard-burned brick, uniform in size and structure, and with true even

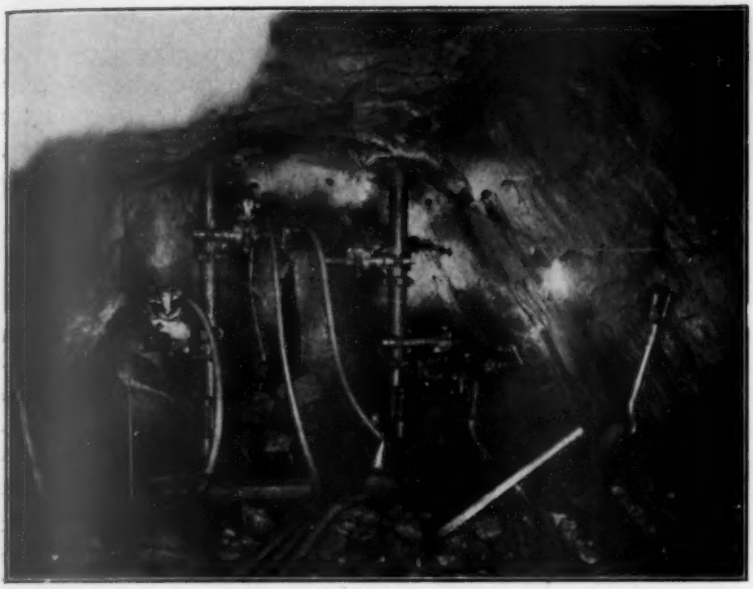

PLATE VII.—Method of Drilling in Hard Rock.

PLATE VIII.—Excavation in Hard Rock, South Heading, Shaft No. 1.

faces." In fact, it was not possible to get the large quantity of brick required in the lining of the tunnel and permanent shafts from one manufacturer, and to meet the conditions, excepting as to size, and avoid delay, two sizes of brick were used. The first brickwork was placed in Section 4, January 3, 1903.

Plastering Brickwork.

Concerning the one-half inch coat of Portland cement plaster on the face of the brickwork in the conduit, which was omitted because it was found impossible to make it continuous from end to end of the conduit by reason of the dampness of the brickwork in the arch, there is some doubt in my mind whether any decided advantage in the smoothness of the interior of the conduit for a great length of time would be accomplished by the plaster coating. The experience of Mr. James M. Gale, Engineer in charge of the Waterworks of Glasgow, who built the second aqueduct which brings the water from Loch Katrine to the Mugdock Reservoir, has raised a doubt of the advisability of plastering a conduit intended to carry a reasonably soft water, such as is the water from the Delaware River. The solvent action of soft water upon the uncombined lime in Portland cement mortar is well known, and it is possible that in due time the Delaware River water would have pitted and roughened the surface of the plaster lining so as to render it less smooth than well laid brickwork with struck and trimmed joints. In the construction of the invert of the tunnel and in the construction of the rings in the shafts, all joints were struck. This, of course, was not possible in the construction of the brickwork of the arch, but upon removing the centers and after the mortar had set, all excess mortar in the soffit joints was carefully trimmed away from end to end of the conduit. While it is true that, at joints in the lining of the conduit, there is some noticeable irregularity or lack of smoothness in the brickwork, this represents a very small portion of the 14,000 feet of conduit, and by far the larger percentage of the shafts and tunnel consists of brickwork as smooth as any that I have ever seen laid in sewer work where the operations were conducted in open cut, and under much more favorable conditions for neat bricklaying than were found in the conduit.

When it became evident that the plastering could not be

made to stick to the brickwork of the arch, about twenty-one per cent. of the total length of arch had been placed, and orders were then issued to the Contractor and the Engineers and Inspectors in charge of the lining, to exercise especial care in building the arch true to line and radius, in view of the probability that the plastering of the brickwork could not be accomplished and that the face of the brick lining would be, upon completion, the wetted perimeter. At least seventy-nine per cent. of the soffit of the arch is as true and smooth as the lining of the invert which was laid to templets with struck joints.

The only real objection to the omission of the cement plastering was the possible reduction of carrying capacity, and if experience should show this to be the result, it would then assume a serious phase. But directly it was demonstrated that the plastering could not be successfully and continuously applied to the arch, extra precautions were taken in laying the brickwork, and upon drawing the centering all excess mortar in the joints was chipped away flush with the face of the arch.

Investigations of the value of "n" in the Kutter formula for flow of water in closed channels, of plastered and unplastered brickwork, seemed to show that "n" = .013 could safely be applied to the unplastered brickwork of the conduit, and if this conclusion is well founded, it should have the full capacity intended, with unplastered arch ten feet seven inches in diameter. As a rule, the invert was a very smooth piece of brickwork, and it is not thought that plastering would have materially improved this in flowing function.

Portland Cement and Concrete.

Only Portland cement was used in all parts of the work, as follows:

24,162	barrels	of	Star Bonneville
9,650	"		Lehigh
675	"		Saturn
450	"		Giant
34,937	"		Total

Concrete was mixed in the following proportions:

For the cradle of invert and packing of arch:
1 part cement
3 parts sand
5 parts broken stone ballast.

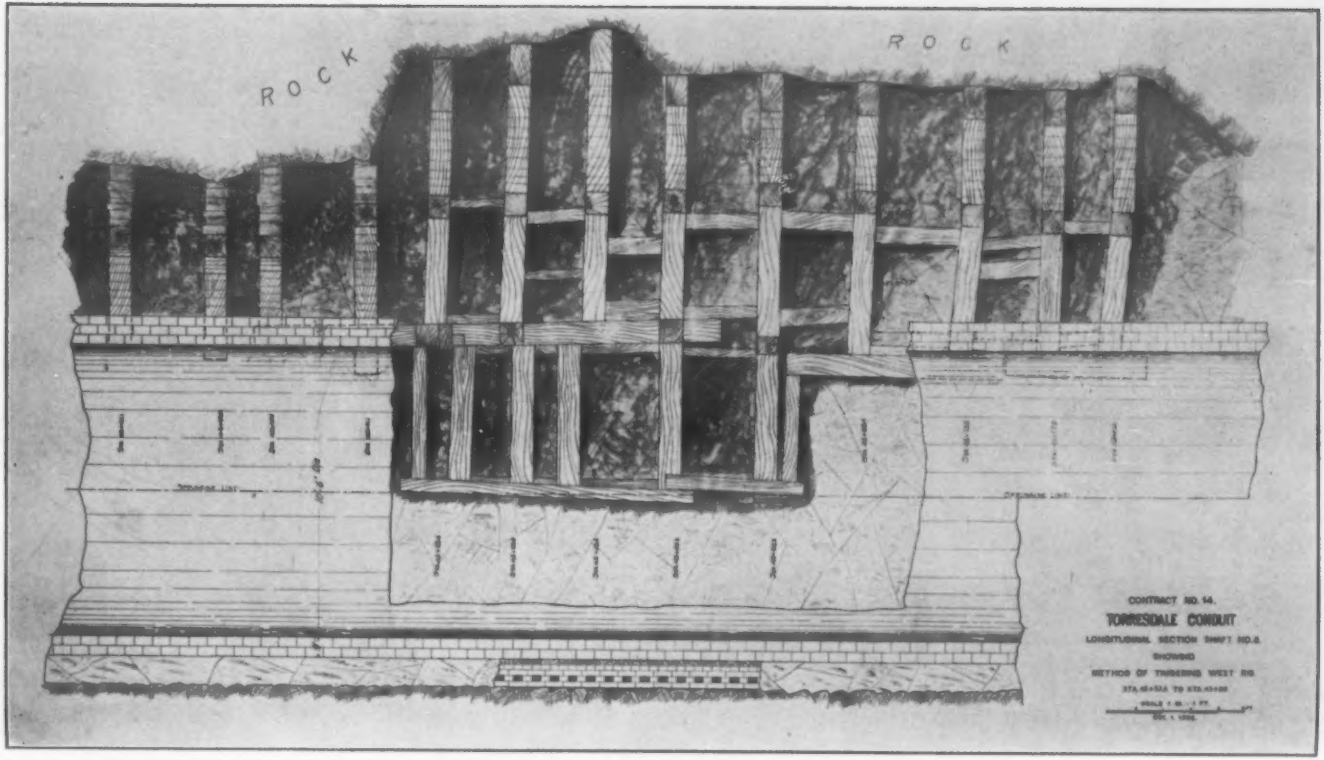

PLATE IX.—Timbering in Soft Rock, North Heading, Shaft No. 8.

For the bends of Shafts Nos. 1 and 11:
1 part cement
1½ parts sand
1½ parts limestone screenings
5 parts broken stone ballast.

Face work of bends:
1 part cement
1 part sand
1 part limestone screenings.

Concrete Cubes.

During the progress of the work 418 concrete cubes were made as samples of the material used in the construction of the cradle and of the arch, and these were broken after 60, 90, 120 days, and six months; and the very best concrete, as shown by the compression tests, used anywhere in the work of the Improvement, Extension, and Filtration of the Water Supply, was used by the Contractor for Contract No. 14, some of the cubes exceeding 5,000 pounds per square inch in the crushing test.

Cost of Work.

Contract price		$1,274,000.00
Extras authorized by City	$68,505.33	
Deduct scrap steel sold and work not performed	546.60	67,958.73
Total Cost		$1,341,958.73
From which deduct plastering not placed		20,735.54
Difference		$1,321,223.19

The probable cost of the work to the contractor from records made of materials furnished and work performed was $1,306,186.62, or $93.10 per linear foot.

The quantities of materials as per original estimate, prior to making of contract, and as actually performed, are shown in the following table:

1 Items	2 Original Quantities From Plans	3 Quantities Actually Performed	4 Increase Over Original Estimate	5 Additional Quantities Not Included in Cols. 3, 4, Ordered as Extras
Excavation—				
Tunnel, cubic yards	83,670	89,366.90	5,696.9	.....
Shaft, " "	5,632	7,425.00	1,793.0	21.0
Concrete " "	22,381	24,058.00	1,677.0	3,278.8
Brick Masonry, cu. yds.	18,802	18,360.45	.....	1,145.7
Plastering, linear feet	14,058	.....	.....	.....
Cast-iron, lbs.	117,640	128,578.00	10,938.0	.....
Steel "	346,374	353,205.00	6,831.0	.....
Clay for puddle, cu. yds.	.....	.....	.....	94.5
Tar paper, single thickness, square feet	.....	.....	.....	619,000.0

The additional shaft excavation was authorized under the provision of the contract which permitted a lowering of the center line of tunnel if found advisable so to do upon sinking Shaft No. 9, which shaft was first driven to the line of tunnel.

The clay puddle was used over the arch of the closures for the working shafts to render these watertight while the mortar in the brick was setting. Two thicknesses of 3-ply tar paper, not included in the original plans, were used over the brick arch where this was laid under wet roof.

Addition to Quantities.

In addition to the above statement of quantities of work performed, there was used, but not incorporated as such in the estimates, the following materials:

34,937	barrels of cement,
9,703,700	bricks,
12,688	cubic yards sand,
16,725	cubic yards ballast,
11,184	linear feet of 6-in. terra-cotta pipe,
138,814	feet B. M. timber.

In apportioning the lump sum bid for the several items entering into the construction of the work, for the purpose of current estimates, the following unit prices were used:

Excavation in tunnel	$ 7.90 per cu. yd.
Excavation in shaft	19.00 " "
Concrete	9.00 " "
Brickwork	13.00 " "
Plastering interior of brick lining	1.475 per linear foot
Castings	.07 per lb.
Steel work	.09 "

Cost of Tunnel Compared to Pipe Line.

Upon the assumption that the cost of the conduit is based on the limit of contract, viz., $1,350,000.00, the cost per linear foot becomes:

$$\frac{1,350,000}{14,030} = \$96.22$$

Relating this to the cost of twelve equivalent lines of 48-inch cast-iron pipe aggregating 38.8 miles, viz., $38.8 \times 5,280 \times \$16.00 = \$3,277,824$.

PLATE X.—Timber Sets in North Heading, Shaft No. 8.

Or, reduced to the length of the tunnel, the cost per linear foot becomes:

$$\frac{3,277,824}{14,030} = \$233.62$$

FATAL ACCIDENTS.

During the construction of the conduit fourteen lives were lost, as follows:

Shaft No. 1.—November 20, 1902—One man killed by the fall of a fragment of rock from the side of the shaft.

Shaft No. 2.—June 2, 1902—Foreman killed while riding down the shaft on a pump which was being lowered to position at the bottom of the shaft, by a piece of pipe which became disconnected and fell.

Shaft No. 3.—August 14, 1902—The pump man at foot of shaft killed by dropping of a drill from the cage in the shaft.

January 10, 1903—One man fatally burned in a shack fired by an explosion of the dynamite stored in the magazine.

Shaft No. 4.—July 31, 1902—One man killed by being struck by the boom of derrick and knocked into shaft.

Shaft No. 7.—May 20 and May 21, 1902—Two men fatally overcome by powder fumes in the heading.

Shaft No. 9.—April 30, 1902—Three men killed at one time by the tipping of a bucket in which they were being drawn up out of the shaft. The hoisting engine developed some trouble, and just as the boom of the derrick was being swung clear of the shaft, the hoisting rope slipped and bucket struck on the upper edge of the steel shell and dumped the men into the shaft.

Shaft No. 10.—April 5, 1902—One man was killed by being crushed between the side of the shaft and the discharge pipe of a pump which was being lowered in the shaft.

Shaft No. 10.—December 2, 1902—One man killed by being hit in the head by a fragment of rock from a blast fired in the south heading 400 feet distant.

Shaft No. 10.—December 4, 1902—One mall killed by fall of rock from the roof in the south heading.

Pennypack Creek.—Between Shafts Nos. 1 and 2, man drowned by leaping from the transfer boat, which he supposed was sinking.

Estimated Carrying Capacity.

Data upon the actual flowing capacity of large brick lined conduits under pressure is very meagre, but with the loss of head between Shaft No. 1, at Torresdale, and Shaft No. 11, at Lardner's Point, of 8.6 feet, it is assumed that the conduit will have a carrying capacity of 300,000,000 gallons per day of twenty-four hours.

By Kutter's formula, with "n" taken at 0.013, the capacity for the given loss of head will be:

$$V = 136.1 \sqrt{2.645 \times .000616} = 5.484 \text{ feet.}$$

$$Q = 5.484 \times 87.97 = 482.427 \text{ cubic feet.}$$

$$G = \frac{482.427}{1.5472} = 311.8 \text{ million gallons per day.}$$

By Lampe's formula:

$$V = 167.89\, r^{.014} \times s^{.555} = 5.455 \text{ feet;}$$

$$Q = 5.455 \times 87.97 = 478.987 \text{ cubic feet;}$$

$$G = \frac{478.987}{1.5472} = 309.6 \text{ million gallons per day.}$$

The capacity, of course, can be increased by lowering the level in the pump wells at Lardner's Point, and increasing the loss of head in the conduit.

The cubic contents of the conduit, taken to the normal level of ground water, 197.00 T. D., is 9,253,932 gallons, and the time required for water to flow from Shaft No. 1 to Shaft No. 11, when the conduit is delivering 300,000,000 gallons per day will be about forty-four minutes.

Comparison of Conduit and Equivalent System of 48-inch Gravity Cast-Iron Pipes.

In order to balance the carrying capacity of the Torresdale Conduit with a system of cast-iron gravity pipe with the same loss of head, it will require twelve lines of 48-inch cast-iron pipe of an average length of 17,100 feet for each line, or a total length of 38.8 miles.

Experience has shown that a leakage of 8,630 gallons per mile per day of twenty-four hours in a line of 48-inch cast-iron pipe, operating under a pressure of fifty pounds per square

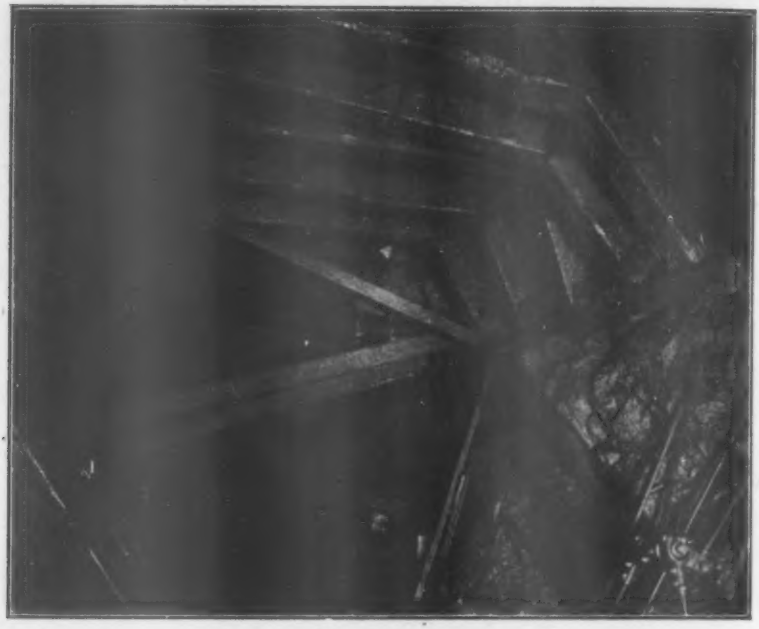

PLATE XI.—Timbering, Shaft No. 8, North Heading.

PLATE XII.—Timbering, Shaft No. 9, South Heading.

inch, is allowable under all ordinary conditions. The head required for a flow of 25,000,000 gallons per day through each of the twelve lines of 48-inch pipe mentioned is 10.3 feet; and prorating the leakage on the square roots of the heads, the allowable leakage for 38.8 miles of 48-inch cast-iron pipe having the same capacity as the Torresdale Conduit, amounts to 100,000 gallons per day of twenty-four hours.

The cost of the cast iron gravity conduit would have been, at the prices prevailing when the conduit was let by contract, about $3,278,000.00, or $1,928,000.00 more than the cost of the structure as built.

The interest charges alone on the difference of cost at 3½ per cent. would have been $67,474.00, while the annual charge due to the probable loss of 200,000 gallons of filtered water per day at $5.00 for filtration and low service pumpage, and $3.84 for interest charges on the Torresdale works, will amount to $6,453.20.

But it has been shown that an allowance of 100,000 gallons per day for the leakage of the cast iron pipes is reasonable, and hence of the annual value of water lost, one-half only should be charged against the conduit, or $3,226.60; about one-twentieth of the interest charges on the increased cost of cast iron gravity pipe lines.

Examination of the Conduit.

After closing the last two working shafts, Nos. 2 and 7, early in April, 1904, and removing the pumping machinery from Shaft No. 1, daily observations were taken from April 8th to the 18th on the rise of water in the tunnel and end shafts.

After plotting the elevations of water level and corresponding leakage it was found that the leakage was greater than was anticipated at the time of removal of the pumps, and more than could be readily accounted for, provided the sump at Shaft No. 1 and all open weepers, had been properly closed.

The contractor's attention was promptly called to the apparent excessive leakage, and after full consideration of the matter it was finally decided to pump out the conduit, make an examination of the interior, and correct any defects or oversights of the contractor's work which such examination might reveal.

THE RESULTS OF EXAMINATION.

After considerable delay in making the necessary arrangements for head house, boilers, and pump to empty the conduit, the work of pumping out was started August 13, 1904, using for this purpose at first a No. 8 DeLaval steam turbine, having a rated capacity of 1,200 gallons per minute under 125 feet head, and later a No. 9 and a No. 11 Cameron shaft sinking pumps. The No. 9 Cameron pump had a capacity of 300 gallons per minute, and the No. 11, Cameron, a capacity of 450 gallons per minute.

The pumps were hung on wire cables from hand winches and chain blocks in such manner that they could be lowered as the water level in the shaft was reduced; and as each pump was lowered by stages in this manner, the three lines of pipe reaching from the ground level to the pumps was increased by adding sections uniformly ten feet in length.

The discharge of the pumps was carried into a tight wooden sluice way and run into a weir box having a width of five feet, a depth of one foot nine inches below the weir crest, and a length of fourteen feet, and provided with the usual screens to smooth the water before it approached the weir, and with a weir having a notch twenty-one inches wide by nine inches deep. The weir was made of brass plate, with sharp edge, set truly plumb, and at right angles to the axis of the weir box, and with the crest level from end to end. The heads on the weir were read by means of an ordinary hook gauge with vernier reading to one-thousandth of a foot, set in a stilling box outside the weir box, and connected with the latter by means of a perforated iron pipe laid across the bottom about three feet up-stream from the weir.

All conditions for accurate measurement of the water pumped from the conduit were carefully observed, the point of the hook gauge being referred to the crest of the weir from day to day by means of a "Y" level and leveling rod.

The same outfit, of course, served not only to measure the rate at which water was being removed from the conduit before it was emptied, but after it was emptied, to gauge the leakage, all of which, of course, was removed from Shaft No. 1 and discharged over the weir.

Observations of the head on the weir, of the level of the

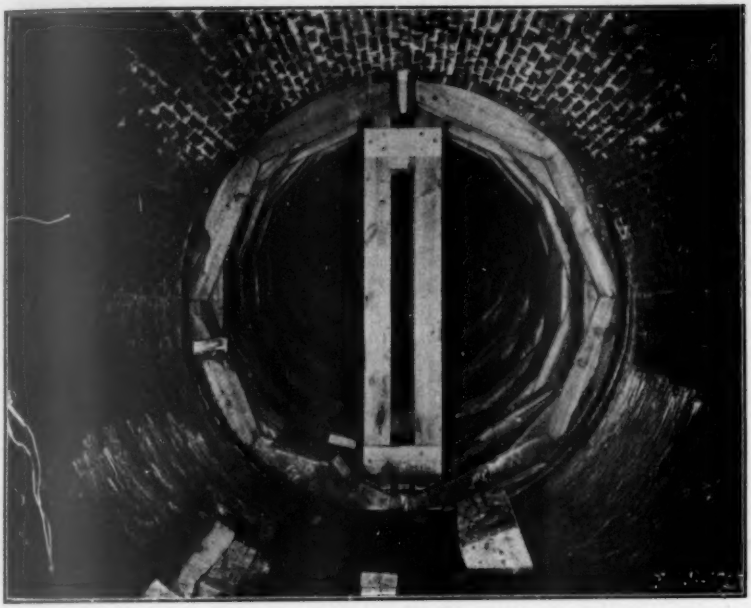

PLATE XIII.—Form for Turning Concrete Bend, Shaft, No. 11.

PLATE XIV.—Lining of Tunnel Looking Towards Shaft No. 2.

water in Shaft No. 1, and of the general conduct of the work, were made hourly, night and day, throughout the operations from the time the pump was started on August 13th, 1904, until December 17th, when the pumps and all other material were removed from Shaft No. 1, and preparations made to close the shaft head, and after this until January 12th, at which time the ground water having reached elevation 193.00 T. D., was rising at such a slow rate as to render further observations unnecessary.

The depth and diameter of the shaft rendered all operations for pumping out and repairing the conduit very difficult. After the two Cameron shaft-sinking pumps, and the DeLaval steam turbine, with their steam exhaust and discharge pipes, had been hung, the remaining space for lowering men and materials was too small for a cage or even a bucket, and only about large enough to accommodate a boatswain's chair suspended from the hook of the derrick. I cannot compliment too highly the riggers and engineers in charge of the derrick for their careful work for the period of 132 days of active operations, during which time no serious accident to men or machinery occurred.

October 20th, 1904, the water was lowered in the conduit until the depth over the invert at Shaft No. 1 was such as to permit of an examination being made from end to end, at which time it was discovered that the sumps at Shaft No. 1 and Shaft No. 2 had not been closed. In addition to the open sumps, considerable water was coming into the conduit through a number of large open joints in the brickwork, and from several particularly wet spots in the arch between Shafts No. 8 and No. 11, but by far the largest proportion of leakage was from the two open sumps, as the gaugings later given will show.

Closing Sumps.

The sump at Shaft No. 1 was closed in the following manner: An opening about eight feet long by five feet wide was cut through the brick invert and concrete cradle for a depth from the center of invert of twenty-four inches. The center of the sump thus formed was further excavated by blasting the rock for a depth of fourteen or fifteen inches to accommodate the suction of the No. 11 Cameron pump, which was arranged to

pump the water away from this sump until it was finally closed. Over the bottom of the excavation coarse gravel and boulders were carefully spread by hand and leveled for a foundation for the casting or "sump closer." On the gravel was set, and lined and leveled, a flared cast-iron box, measuring six feet, six and one-half inches in length, by three feet three and one-half inches in width over the lower flange, and five feet ten and one-half inches in length, by two feet six and one-half inches in width over the upper flange, with an anchor flange at mid-height having a mean of above dimensions.

The internal dimensions of the box were five feet seven and one-quarter inches long at the bottom, and five feet long at the top, by two feet four and one-half inches wide at the bottom, and one foot eight inches wide at the top. Across the casting at midlength a bridge was cast.

The upper flange was planed and drilled for one inch diameter studs, and the casting was closed by a cover divided at midlength with a sharp "V" shaped groove for lead joint at the junction of the two plates.

The box was everywhere one and one-quarter inch thick, and the cover one and one-half inch thick.

One section of the cover plate was bored, drilled and tapped in the center for a six-inch union flange, and short six-inch nipple with a flange on the top to accommodate the suction of the Cameron pump.

The casting was leveled on the gravel base; the water pumped down to and maintained at the level of the lower flange, and the box concreted in place, leaving, of course, the center open to serve as a sump until the opening was finally closed. After the concrete had set for two weeks, the cover plates were bolted down on white pine gaskets; the "V" opening between the plates caulked with lead, and the pump suction reduced in size and set in the six inch riser in one of the cover plates. The riser, upon removal of the pump, was closed with a six-inch flange bolted down on a white-pine gasket.

To bring the water freely from the sides of the sump to the center of the casting, short lengths of old four-inch boiler flues were set in place as the gravel was laid.

When the sump was closed, it was perfectly water-tight. All the work connected with the placing, concreting, and final

PLATE XV.—Top Section of Steel Shell, Shaft No. 11.

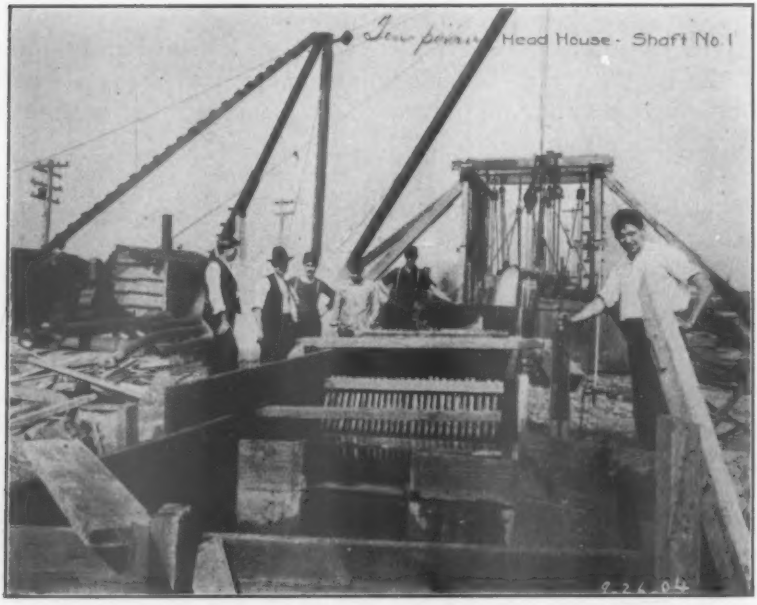

PLATE XVI.—Temporary Head House, Shaft. No. 1.

closing of the casting was performed under the supervision of Mr. John E. Powell, Superintendent in charge of repairs.

At the open sump at Shaft No. 2 a different plan was adopted. Here the original plan was to square the opening carefully to the smallest possible dimensions; fill the hole with coarse gravel, set above it on the invert a stout wooden form braced down and made watertight by caulking around the edges, and pump grout into the opening under fifty or sixty pounds' pressure through a two-inch pipe set in the form. In cutting out the hole the workmen misunderstood orders and made the sump large enough to receive the form. This mistake or blunder caused at least two weeks additional work, and largely increased the cost and difficulty of closing the sump.

Several expedients were adopted and failed of the purpose, and finally a No. 4 centrifugal pump of 400 gallons capacity per minute was set up near the sump. An alternating current motor was procured and set up on a temporary timber platform, and belted to the pump, and the current to operate the motor carried in from Shaft No. 1, a distance of 1,400 feet. The suction of the pump was then set in the bottom of the sump, and the discharge set in a sluice box which delivered the water north of a temporary sand bag and clay dam placed north of the sump.

A similar dam was built south of the sump, and the water from south of Shaft No. 2 flumed across the opening under the shaft.

When the pump was put in service, delivering about 350 gallons per minute, the sump and invert of the conduit were laid dry, and operations to close the sump permanently commenced.

In the center of the sump, on a coarse gravel foundation as at Shaft No. 1, a short length of twelve-inch steam pipe with a flange top and bottom was set, with the upper flange about five inches below the line of tunnel invert. In this nipple was set the suction pipe of the centrifugal pump, which was operated constantly day and night to keep the opening dry.

Railroad bars cut about four feet long were placed at right angles and diagonally across the opening above the lower flange of the twelve-inch nipple, and securely anchored at the ends under the old concrete cradle of the conduit. Concrete

was then rammed in the dry hole up to the level of the upper flange, around the nipple, and up to the line of the invert around the hole outside the nipple. The nipple, after the concrete had set for over a week, was closed with a blank flange bolted down on a white-pine gasket, and the depression of four or five inches over the cap finished to the line of the invert with a fine cement mortar.

This sump when closed was perfectly watertight.

When the sumps were closed a portion of the water which previously issued from them, forced its way through the concrete and brickwork between Shafts Nos. 1 and 3. The work at Shaft No. 2 was also conducted under the supervision of Mr. Powell.

In anchoring in place with concrete, the sump casting at Shaft No. 1, and the nipple at Shaft No. 2, due consideration was given to the pressure which would come upon them when closed, and the water forced to seek other, though less convenient, points of efflux.

The hydrostatic pressure of the water in the rock at the bottom of the conduit was roughly forty-three pounds per square inch, and the upward pressure on the sump casting at Shaft No. 1, and on the nipple and railroad bars at Shaft No. 2, was estimated at over forty tons in each instance.

The necessity of operating a power pump at Shaft No. 2 so far from the only open shaft at the north end of the conduit, imposed an unusual difficulty, and nothing in all probability could have satisfied the conditions so well as the electric current and motor employed.

Many open weepers and joints in the brickwork were found, and all these were carefully closed with poplar plugs and white pine wedges, and where considerable water flowed in spots from the roof or arch, holes were jumpered through the brickwork and concrete, iron pipe driven in, and grout pumped over the arch under pressures up to 100 pounds per square inch.

Grout was used generally in the proportion of four parts of cement to one part of fine sand, although in some cases the sand was omitted.

Upon entering the conduit, considerable dirt, debris, timber, and loose brick from the construction work was found lying

PLATE XVII.—Foot of Shaft No. 1.

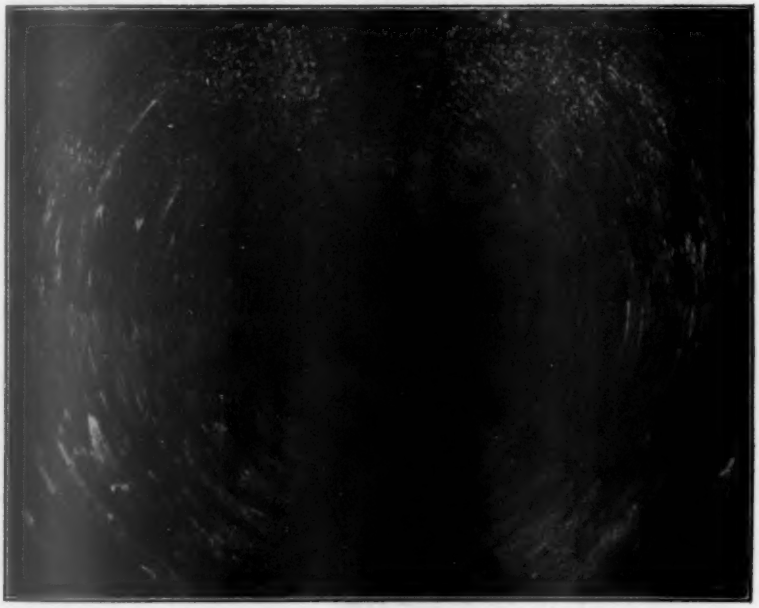

PLATE XVIII.—Lining of Tunnel under Shaft No. 2.

on the invert. Planks left in the tunnel had become water-logged and impregnated with iron from the rock water, and lay on the invert. All this material was removed, slush from the cement mortar used in laying the brickwork carefully washed out, and removed either at Shaft No. 1 or Shaft No. 11, whichever happened to be nearest.

In closing the shafts after the pumps, pipes and other hamper were removed, steel buckle plates one-quarter inch thick, bent to the intrados of the brick arches, were set on the lower flanges of the "I" beams spanning the shafts, and left in place after the brick arches were turned and covered with concrete. This was done to avoid the use of wooden centers, which could not conveniently be removed after the arches were turned.

It is probable that all the real work performed in closing the sumps and weepers, and in plugging open joints in the brickwork, and in grouting over the arches, could have been performed by the contractor before he drew the pumps from Shaft No. 1, at a cost of $1,000.00, while the operations performed under unusual difficulties, of installing new pumping machinery, hoisting apparatus, steam and water pipes, electric currents, etc., including all labor of cleaning out the conduit, cost over $22,000.00, illustrating the old adage that "Haste makes waste," and the other old adage, "that what is not in a man's head is in his heels."

Measuring the Leakage.

Information on the leakage of structures like the Torresdale Conduit is very meagre; few such conduits have been built, and very little data recorded of the water lost or gained either during or after construction, and of the structure in service. The inverted siphon of the Second Croton Aqueduct under the Harlem River; the Washington Aqueduct, and the Jersey City Conduit, are examples in point; ordinary railway tunnels are not comparable to the Torresdale Conduit, because the former are nearly always cut through elevated ridges or knobs much above tide level, are usually self-draining, and not subject to the influences of the water level in nearby streams at higher elevation than the line of the work. Exceptions may be noted in railway tunnels which pass under rivers like the St. Clair

Tunnel at Detroit, the tunnels under the Chicago River at Chicago, and under the Thames in London. The Wachuset Aqueduct, which is a similar structure, I am advised by Mr. Frederick P. Stearns, Chief Engineer of the Metropolitan Water Board, Boston, was not tested for watertightness. No evidence of leakage is known to exist, but no data have been recorded to prove absolute watertightness of the structure. No data are to be found in the office of the City Engineer of Chicago, showing either construction or service leakage of the Lake Tunnels. It is probable that these are practically watertight, because they are driven through a tough impervious clay. In the construction of the Cleveland Tunnel compressed air was used, and, aside from this, the material through which the tunnel is driven was a tough clay, practically impervious, and therefore not comparable with the tunnel driven through such material as was found in the line of the Torresdale Conduit.

Gauging in Empty Conduit.

The gauging in the empty conduit was done with a fifteen inch brass weir screwed to the face of a two-inch plank, about seven feet long, cut to the radius of the invert five feet three and one-half inches. The weir plate was accurately constructed with a sharp edge uniformly fifteen inches long, with a depth of notch of six inches. After this had been carefully set plumb at right angles to the axis of the conduit, with the crest of the weir level, and secured in position by bracing against the arch, and by the use of sand bags placed on the down stream side of the weir clear of the notch and overfall, the joint between the segment of the plank and the brickwork was made tight with clay, so that all water was required to pass through the notch of the weir. The gauging was done by measuring from a stiff arm attached to the top of the weir board and extended about two feet up-stream, carrying at its end a thin, vertical strip of wood with small wooden lug at the bottom. The lug was in each case carefully adjusted to the level of the crest of the weir by a straight edge and spirit level, and fixed firmly in position. The depths on the weir were gauged by means of a thin steel rule set on the lug. The accuracy of adjustment of the lug was tested before and after readings were taken, and the depth on the weir was determined

PLATE XIX.—Lining of Tunnel under Shaft No. 3

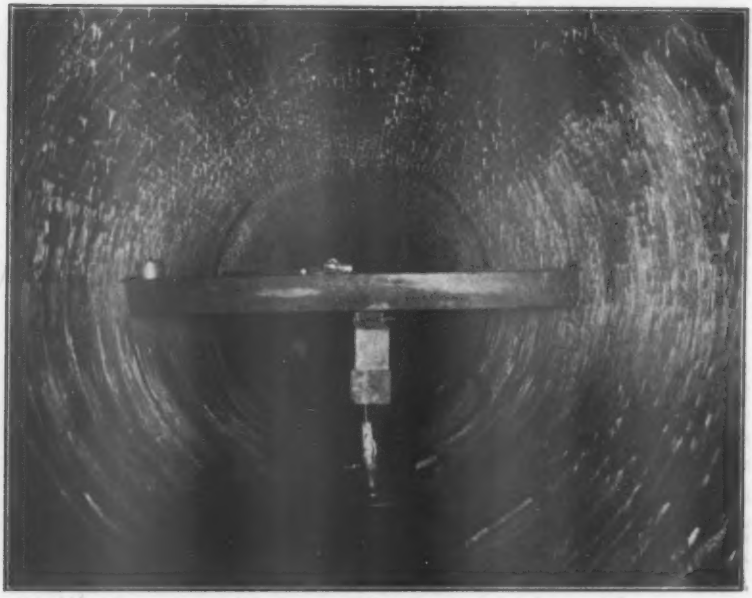

PLATE XX.—Closing Weeper in Invert, Shaft No. 3.

by taking the submerged length of the rule from the lug to the level of the water.

Readings of the flow in the tunnel were taken at intervals of fifteen minutes, and until they showed no further increase in the head on the weir. After the regime of water flow was established in this manner, the weir was then moved to a new station. The heads noted on the weir at different points were converted into volumes of flow after the formula—

$$q = c \tfrac{2}{3} l \sqrt{2g}\, b\, H^{\frac{3}{2}}$$

In the following table are given the final gaugings taken before the pumps were removed from Shaft No. 1. The notes from stations south of Shaft No. 2 were taken before all the operations for reductions of the leakage had been completed, but the gaugings at Shaft No. 2, and at the top of Shaft No. 1, took into account all the water flowing at the respective stations, which included for Shaft No. 2, all leakage between that station and Shaft No. 11, and the gauging at Shaft No. 1, of course, included all water coming from the conduit. It is thus probable that the leakage south of Shaft No. 2 was less than the table shows, and the leakage from Shaft No. 1 to Shaft No. 2, correspondingly more than 364 gallons per minute.

Station	Length of Tunnel Embraced in Gauging Lin. Ft.	Flow for Station Gals.	Accumulated Flow at Station. Gals.
At Shaft No. 11	0	9	9
Between Shafts 9-10	1557.81	84	93
" " 8- 9	1345.00	23	116
" " 7- 8	1607.50	81	197
" " 6- 7	1537.50	57	254
" " 5- 6	1557.00	92	346
" " 4- 5	1508.00	84	430
" " 3- 4	1442.00	44	474
" " 2- 3	1238.00	162	636
From midway between Shafts 2-3 to, and including, Shaft No. 1	2016.00	202	838

Of the 838 gallons per minute for the whole conduit, 364, or over 40 per cent., occurs between Shaft No. 1 and midway between Shafts Nos. 2 and 3, a distance of 2016 linear feet.

For a period of fifteen days—June 1 to 15, inclusive, 1903, —at a time when the water from Shaft No. 1 and its connected headings was being pumped separately, i. e., when the water from one section of the work was not allowed to flow to and

be pumped from another section, the average leakage was, at

	Galls. per min.
Shaft No. 1	350
" 2	336
" 3	122
Total	808

For a period of fifteen days—June 16-30 inclusive:

Shaft No. 1	294
" 2	416
" 3	102
Total	812

For a period of fifteen days—July 1-15 inc.—

Shaft No. 1	248.2
" 2	362.8
" 3	96.0
Total	707.0

For a period of sixteen days—July 16-31 inc.—

Shaft No. 1	305
" 2	328
" 3	95
Total	728

For a period of fifteen days—August 1-15 inc.—

Shaft No. 1	319
" 2	340
" 3	94
Total	753

For a period of fifteen days—August 17-31 inc.—

Shaft No. 1	244
" 2	346
" 3	96
Total	686

For a period of fifteen days—September 1-15 inc.—

Shaft No. 1	277
" 2	324
" 3	98
Total	699

For a period of fifteen days—September 16-30 inc.—

Shaft No. 1	228
" 2	327
" 3	89
Total	644

These gaugings were not taken with the precision of those

PLATE XXI.—Lining of Tunnel under Shaft No. 4.

PLATE XXII.—Lining of Tunnel under Shaft No. 5.

upon which the present leakage of the conduit is based, but are deemed sufficiently accurate for the present purpose, and comparing these leakages with the leakage for the same sections after the operations connected with the examination and repair of the conduit were completed, viz., 408 gallons per minute, will show a reduction of 44 per cent. A part of this reduction, of course, must be credited to the arching of the tunnel and relieving arches under the working shafts, which, however, would apply only to Shafts Nos. 2 and 3.

Upon closing the working shafts prior to April 8, 1904, readings were promptly taken of the elevation of water in the conduit at Shaft No. 1, and later at Shaft No. 11, when it rose to sufficient height to be gauged from the iron staging in the latter shaft with results as follows:

On April 8th (the first day of gauging) the elevation of water in Shaft No. 1 was 95.467 T. D., or 6.397 feet above the invert of the arch.

By April 18th, during a period of ten days, the water had risen to an elevation 182.15 T. D., at which time it was thought that the rate of inflow was too great to be accounted for upon the supposition that the sump at Shaft No. 1 and all weepers had been closed.

Prior to closing the last three working shafts, viz., Nos. 2, 7 and 9, the flow of water from the sump at Shaft No. 1 was very large, and it was though that, excepting with great care upon the part of the workmen, this sump would either not be effectually or neatly closed, and investigations were therefore begun to determine whether the last efforts necessary to reduce the leakage to a minimum had been properly made.

The best gaugings previous to closing the last three working shafts (April, 1904.) indicated a probable flow of 922 gallons per minute, divided as follows:

Station	Distance between Stations Linear Ft.	Leakage Each Station Ga's.	Accumulated Leakage Gals.
From Shaft 9 to 11	2121.81	42.2	42.2
" S8 to 9	790.00	17.8	60.0
" S7 to N9	1607.50	20.0	80.0
" S6 to N8	1593.60	40.0	120.0
" S5 to N7	1452.50	92.0	212.0
" S3 to N6	2939.29	74.0	286.0
" 2 to N4	1952.10	391.0	677.0
From midway between 1-2 to 2	675.68	43.0	720.0
From No. 1 to midway between 1-2	675.69	202.0	922.0

Gaugings between all the shafts, previous to placing the larger portion of the brick lining and concrete backing, determined by the operation of the pumps at each of the respective shafts, gave leakages as follows:

Shaft	Gallons Per Minute
1	517.50
2	312.00
3	267.00
4	85.00
5	125.00
6	120.00
7	145.00
8	175.00
9	110.00
10	155.00
11	64.00
	2175.50

Comparing the last gaugings (December, 1904,) with these leakages, which generally represent the unrestrained flow of water through the shattered rock after blasting at the headings and benches, the reduction of the inflow of water amounts to about 61.50 per cent.

Considering Shafts Nos. 1, 2 and 3, the gaugings made during the first three months of 1903, in advance of the lining of the tunnel, show an average leakage of 1196.50 gallons per minute, and compared to the last gaugings taken after the lining was about completed, but before the working shafts were closed, (October, 1903), show a reduction of 46 per cent., and compared with the December, 1904, gauging, a reduction of 70 per cent.

Elevation of Ground Water.

While the elevation of ground water has been assumed at 198.00 T. D., or slightly above high tide in the Delaware River along the line of the conduit, the gaugings taken last April after the conduit was closed, and since December 17th, when the repairs on the work were completed and the pumps and machinery removed, indicate that this may be too high, and that the mean level of ground water along the line of the conduit is not coincident with or above high tide. Of course considerable time will be required for the water to atttain its normal level, but assuming that it may be 197.00 T. D., then the difference between the maximum elevation of water in

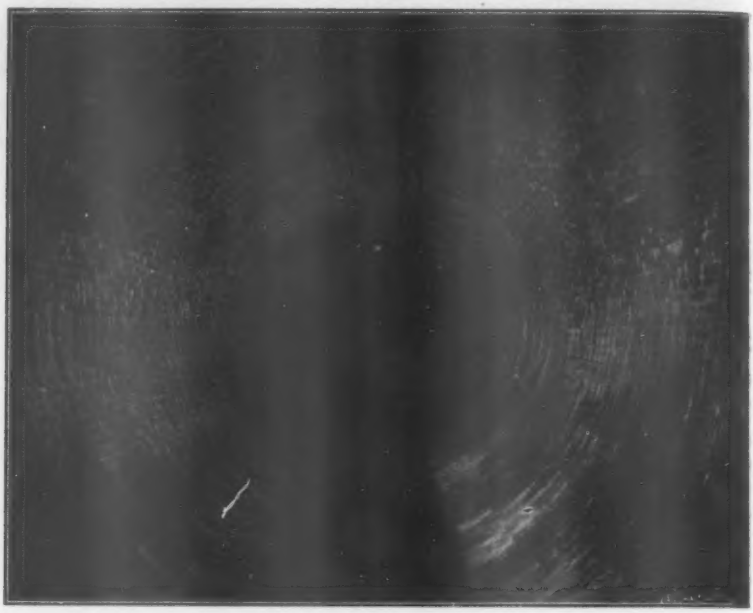

PLATE XXIII.—Lining of Tunnel under Shaft No. 6.

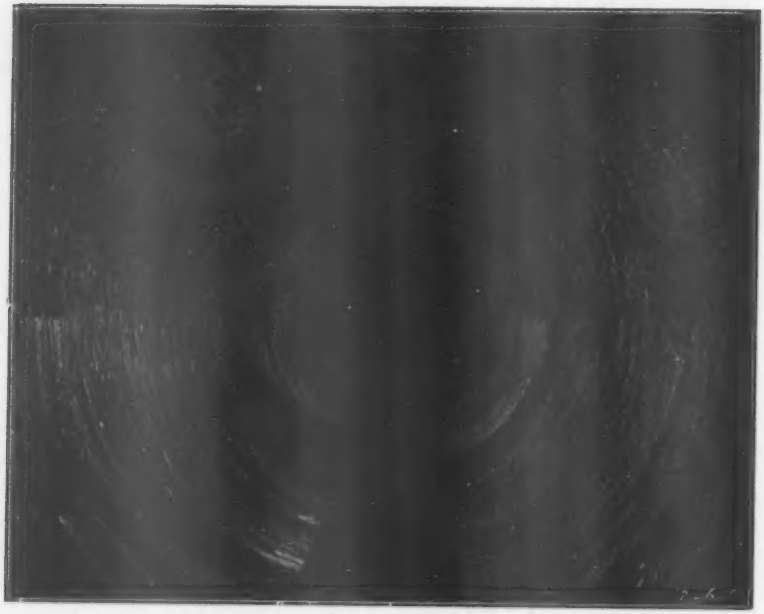

PLATE XXIV.—Lining of Tunnel under Shaft No. 7.

Shaft No. 1 and ground water will be ten feet, i. e., the head on the inside of the conduit will be ten feet greater than the water in the drift and rock on the outside of the conduit.

At elevation 190.00 T. D., or seven feet below probable normal elevation of ground water, the known leakage into the conduit since the sumps and open weepers have been closed, and particularly bad spots in the roof grouted under pressure, was at the rate of sixty-five gallons per minute; and, reasoning by analogy that when the water in the conduit is at mean elevation, Shafts No. 1 to No. 11, of 202.70 T. D., or 5.7 feet above assumed elevation of ground water, the leakage would be no greater, it would then appear that the daily leakage will not be in excess of 93,600 gallons, or, say, 100,000 gallons per day, an amount which would readily be allowed for an equivalent system of cast-iron pipes operating under the same conditions.

Watertightness.

In preparing the plans and specification the term "watertightness" was frequently used. This was meant watertightness within the limitations of the materials to be used in lining the permanent shafts and tunnel, and no arbitrary leakage was fixed in the specification, because it was not possible, in advance of driving the headings to make an accurate calculation of the amount of water that would be encountered. It was known from the diamond drill borings along the line of the work that water would be found in the drift and rock at certain depths, and an effort was made to show at what depths water would be found, and to indicate whether the flow was large or otherwise. The diamond drill borings that preceded the preparation of the plans for the work were conducted not so much, however, to determine the presence of water in the rock as to indicate the character of the rock, and to furnish data upon which to fix the center line of the tunnel.

Considering the elevation of the center line of the conduit with reference to sea level or mean tide in the Delaware River, it should be obvious that the rock was bound to contain a considerable volume of water, and that when headings were driven into it, a flow would be encountered, the quantity of which, however, could not be determined in advance. In close grained

rock, without fissures, and with little injury to seams in blasting, the flow would naturally be much less than if the rock was porous, heavily fissured, and considerably disturbed in carrying on the operations of tunneling. Therefore, it was impossible at the time the specification was prepared, to indicate any standard for leakage, but the intention was to reduce this to the least possible quantity in a brick-lined tunnel and shafts, thoroughly backed with first-class concrete.

Considering that the mean center line of the tunnel is over 100 feet below ground level, and about 100 feet below mean tide in the Delaware River, it would scarcely be reasonable to assume absolute watertightness for a work so constructed, nor is there any evidence before me, and I have sought it in records of similar works in this country and abroad, that masonry conduits of this description have ever been even approximately watertight, excepting as in the case of the Cleveland and Chicago Lake tunnels, where they are driven through a tough, impervious blue clay, and, as I am informed, no serious trouble was experienced from ground water during construction.

Under conditions of service, assuming the elevation of the water in Shaft No. 1 as 207.00 T. D., and the elevation of the water in Shaft No. 11 as 198.00 T. D., then the mean elevation of the hydraulic grade line of the conduit will be 202.50 T. D. Taking normal ground water level at 197.00 T. D., the mean unbalanced head throughout the length of the conduit would be five and one-half feet. Proportioning the leakages on the square roots of the heads with the conduit in service, and with the conduit empty:

$$838 \times \frac{\sqrt{5.5}}{\sqrt{103}} = 193.60 \text{ or say } 200 \text{ gallons per minute, or}$$

288,000 gallons per day, or less than $\frac{1}{10}$ per cent. of the carrying capacity of the conduit.

It has already been shown that the rate of leakage does not vary as the sq. root of the heads, but as some different function of the head, the value of which, for lack of time, has not been determined. In the absence of an expression which will fit the conditions of rise of water level and leakage into the conduit, such comparisons as will be made with other conduits under

PLATE XXV.—Lining of Tunnel under Shaft No. 8.

PALTE XXVI.—Lining of Tunnel under Shaft No. 9.

pressure will be upon the assumption that the leakage does vary as the square roots of unbalanced heads.

Considering structures which bear a similarity to the Torresdale Conduit:

The Jersey City Conduit is a structure eight feet six inches internal diameter, lined with concrete. Section 1 has a length of 4,600 feet, of which 1,600 feet is in tunnel through shale and sand stone, and 3,000 feet in open cut. The leakage of this during construction amounted to 134,000 gallons per day of twenty-four hours.

Assuming that it was fairly distributed through the entire length of the work, this would give for the length and diameter of the Torresdale Conduit:

$$\frac{134{,}000 \times 10.58 \times 14{,}000}{8.5 \times 4{,}600} = 507{,}623 \text{ gallons per day or } 352.5 \text{ gallons per minute.}$$

Section 4, of the same work, the Watchung Mountain tunnel, 7,300 feet long, is constructued entirely in tunnel, probably through the same material as was found in the tunnel operations on Section 1. The leakage of this section was at the rate of about 2,000,000 gallons per day of twenty-four hours, and the corresponding leakage for the Torresdale Conduit would be:

$$\frac{2{,}000{,}000 \times 10.58 \times 14{,}000}{8.5 \times 7{,}300} = 4{,}774{,}214 \text{ gallons per day, of twenty-four hours, or } 3315.4 \text{ gallons per minute.}$$

The head of the ground water in Section 4 of the Jersey City Conduit is probably 160 feet, and, correcting the leakage on the square roots of the heads, the corresponding leakage for a tunnel of the length and diameter of the Torresdale Conduit, and under the same water head, would be:

$$4{,}774{,}814 \times \frac{\sqrt{103}}{\sqrt{160}} = 3{,}828{,}919 \text{ gallons per day, or } 2{,}659 \text{ gallons per minute.}$$

The New York Shaft of the Harlem River Conduit has a present leakage of about 300 gallons per minute. This is leakage from the aqueduct shaft to a pump shaft designed for use as a sump, and cannot very well be compared to the Torresdale

Conduit, because in one case it is a structure under a head, when empty, of over 103 feet, while the other is a shaft having a head varying from 0 to the depth of the shaft. If any attempt was made to compare the depth and diameter of the New York shaft with the length and diameter of the conduit, it would then appear that the allowable conduit leakage would be enormous, as shown hereafter, and it would be better to consider the leakage of the New York shaft in service with the probable leakage of the Torresdale Conduit when in service, because the leakage reported for the shaft at the New York end of the Harlem River Siphon is service leakage, and not leakage of the empty structure.

Comparing the New York shaft of the Harlem River Siphon (which is twelve feet three inches in diameter, 318 feet deep,) for water depth and diameter with the length and diameter of the Torresdale Conduit, and assuming losses of water or leakage proportioned to the square roots of the respective water heads, we have the following as the corresponding leakage of the conduit:

Wetted surface of Harlem Shaft:

$$38.48 \times 318 = 12{,}236.64 \text{ square feet.}$$

Wetted surface of Conduit:

$$33.25 \times 14{,}000 = 465{,}500 \text{ square feet.}$$

Ratio of wetted surfaces:

$$\frac{466{,}500}{12{,}236.64} = 38.12$$

Ratio of mean square roots of effective water heads:

$$\frac{\sqrt{103.48}}{\sqrt{141.37}} = \frac{10.17}{11.89} = 0.855$$

and the corresponding leakage of conduit based on Harlem River Shaft would be:

$$300 \times 38.12 \times 0.855 = 9{,}777.78 \text{ gallons per minute,}$$

or 14,080,000 gallons per day of twenty-four hours.

The Buffalo Conduit, or intake, which conveys the water from a pier at the head of the Niagara River into the pump well of the Buffalo Pumping Station, is a structure blasted through the Niagara limestone, cut to a section about 8x8 feet, and unlined. The intake is 1,020 feet long, and during construction leaked at the rate of 1,000,000 gallons per hour,

or 24,000,000 gallons per day, equivalent to 16,667 gallons per minute. The tunnel is about sixty-five feet below the surface of the ground, and probably about sixty feet below the level of water in the Niagara River.

Omitting the large flow of water mentioned above, which came from another source than the river, the leakage was said to be very small—not over 500 gallons per minute when the tunnel was empty or pumped out. Of course, when the tunnel was filled there was probably no leakage at all, because the pressure of water inside and outside would be quite the same.

Neglecting the difference of sections and effective heads of water, and proportioning leakage on lengths only, and assuming the least recorded leakage, the Buffalo Conduit for a length equal to the Torresdale Conduit, both considered as empty structures, should have leaked at the rate of 6,863 gallons per minute, or at about eight times the rate of known leakage for the empty Torresdale Conduit.

During the year 1903, *Atlantic City, New Jersey,* laid a wood-stave pipe, forty-two inches diameter, 9,807.4 feet long. This was tested for watertightness when completed under ten pounds pressure, and gave a leakage at the rate of seventy-eight gallons per minute.

Comparing this to the Torresdale Conduit, and assuming the leakage to bear some relation to the internal surface of the pipe and conduit, and that it should be proportioned on the square roots of the respective heads, then the leakage for the Torresdale Conduit compared to the Atlantic City wood-stave pipe would be 164.25 gallons per minute.

A wood-stave pipe should be as tight as a steel riveted pipe, and should represent the minimum leakage for water-carrying conduits, and yet it is evident that this leakage under the conditions of test (which I understand are substantially the conditions of service) is greater than the service leakage anticipated for the bricklined Torresdale Conduit.

An equivalent in carrying capacity of the Torresdale Conduit, as stated heretofore, would be 38.8 miles of 48-inch cast-iron pipe. An allowable leakage of 10,000 gallons per mile per day of 48-inch pipe under a pressure of fifty pounds per square inch has been a standard to which the Bureau of Filtration has endeavored to lay the various water pipes about filters

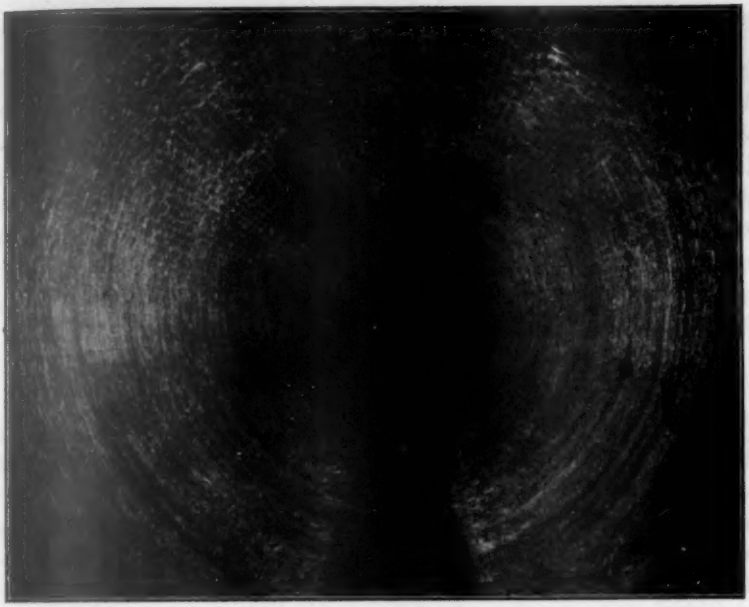

PLATE XXVII.—Lining of Tunnel under Shaft No. 10.

PLATE XXVIII.—Lining of Tunnel under Shaft No. 11.

and reservoirs and in the distribution systems, and assuming this value to apply to the lines of cast-iron water pipe which would have been required to balance in carrying capacity the Torresdale Conduit, the daily leakage then would be 388,000 gallons per day. The pressure on the empty conduit amounts to about 44.61 pounds per square inch, and, proportioning this upon the square roots of the pressures, an allowable daily leakage for the conduit empty compared to cast-iron lead-jointed pipes, made up in twelve foot lengths, would be:

$$\frac{388{,}000 \times 6.679}{7.071} = 366{,}448 \text{ gallons per day.}$$

The leakage of cast-iron pipe is presumed to occur only at the joints, which are spaced about twelve feet apart. In the case of the conduit, however, every brick in the lining is surrounded by a mortar joint, and if the leakage of cast-iron pipe is reduced to the leakage per linear foot of joint, and then compared with the leakage per linear foot of mortar joints in the intrados of the invert and arch of the conduit, we will have the following result:

Linear feet of lead joint per mile of cast-iron pipe:

$$\frac{48 + 2.5 \times 3.1416 \times 5280}{12 \times 12} = 5817.2 \text{ feet.}$$

Allowing 10,000 gallons leakage per day per mile:

$$\frac{10{,}000}{5817.2} = 1.719 \text{ gallons per linear foot of lead joint.}$$

The mortar joint per linear foot of conduit is 49.873 feet for the circular joints and 159.60 feet for the axial joints, or a total of 209.47 linear feet.

Taking the leakage of the conduit empty as 838 gallons per minute, or 1,207,000 gallons per day of twenty-four hours, and proportioning the leakage on the square roots of the pressures, fifty pounds for the cast iron pipe, and forty-three pounds (in round numbers) for the empty conduit, then the leakage per linear foot of joint in the conduit will be:

$$\frac{1{,}207{,}000}{209.47 \times 14{,}000} \times \frac{\sqrt{50}}{\sqrt{43}} = 0.44 \text{ gallons,}$$

and the ratio of leakage per linear foot of joint:

$$\frac{1.719}{.44} = \text{about } 4.$$

Considering the two classes of structures—one with joints everywhere throughout its length and circumference, and the other with joints occurring only at intervals of twelve feet—this is an interesting, if not the correct, method of comparison.

The gaugings for the return of ground water to the conduit since December 16, indicate that at elevation 190.00, which is seven or eight feet below normal ground water level, the leakage was practically nil, or from the records less than forty gallons per minute, showing that the theory of flow upon the square roots of the unbalanced heads will not apply.

Moreover, if it be assumed that the leakage upward for an unbalanced head of seven or eight feet would be no greater than the inward leakage for the same difference of heads between the water in the conduit and the water in the rock, the leakage then under conditions of service should be even less than the amount above mentioned. Of course, exactness in this cannot be stated at the present time, nor until the conduit is in service and exact gaugings made, based upon the displacement of the pumps at Lardner's Point.

The probabilities are that the leakage with the conduit in service will be so small that the most accurate system of gaugings for the water flowing into Shaft No. 1, and for the water flowing out of Shaft No. 11, would not indicate a difference, i. e., the relation of forty gallons a minute to 300,000,000 gallons a day, or 208,333 gallons per minute, is such that the best known methods of guaging would not show a loss of $\frac{2}{100}$ of one per cent. of the flowing capacity between the two ends of the conduit. Even if the loss was as high as 200 gallons a minute, as figured on the basis of the square roots of heads, it would only be five times this quantity, or $\frac{1}{10}$ of one per cent. of the flowing capacity of the conduit, an amount entirely too small to be indicated with any method of gauging the flow of the conduit which could be conveniently applied.

As interesting data upon the leakage of water pipes, which bear some relation to the Torresdale Conduit, Mr. Brush reports in the "*Transactions* of the American Society of Civil Engineers" for 1888, sixteen miles of cast-iron main, varying from four to twenty inches in diameter, laid after the usual manner, as having a leakage of 750,000 gallons per day, or 47,000 gallons per day per mile.

This I should regard as a very large leakage, considering the size of the pipe.

He also reports for eleven miles of 24-inch main, a leakage of 70,000 gallons per day, or 6,364 gallons per mile, equivalent to 12,728 gallons per mile per day for 48-inch pipe. This leakage is in excess of that allowed for cast-iron pipe under the rules of the Bureau of Filtration.

Mr. Loweth in the "*Transactions* of the American Society of Civil Engineers" for 1897, reports a ten-inch pipe leaking at the rate of six hundred to eight hundred gallons per day, equivalent to 3,360 gallons per day per mile of 48-inch pipe. I do not remember that the narrator locates this pipe, nor that the figures given are the results of test. My impression is that this is what he would regard as an allowable leakage for such a pipe.

Mr. John R. Freeman, in his report to the City Controller on the Water Supply of New York, gave as data attained from Fall River, eighty-five miles of mains under from eighty to 120 pounds pressure per square inch, with a leakage of 850,000 gallons per day. This includes not only the water pipes, but also the plumbing fixtures, and is equivalent to 10,000 gallons per day per mile of pipe. Since the larger percentage of this pipe is under 24-inch diameter, it is apparent that the leakage is excessive.

In the same report Mr. Freeman mentions Woonsocket, Rhode Island, with forty-five miles of cast iron mains, under eighty pounds pressure per square inch, and a leakage of 218,400 gallons per day, including plumbing fixtures, equivalent to 4,853 gallons per day per mile of pipe. Considering that these pipes probably range from four to twenty-four inches in diameter, this leakage is excessive.

Prof. Gardner S. Williams, in the "*Transactions* of the American Society of Civil Engineers" for 1897, gives, from his experience in the Detroit Water Works, for a system of pipe four, six and ten inches in diameter, average diameter 6.06 inches, 20,607 feet long, a leakage under ninety pounds pressure of 599 cubic feet in twelve hours, equivalent to 8,961 gallons per day, or 2,300 gallons per mile. Relating this to a 48-inch main would produce a leakage of 18,210 gallons per day per mile under the stated pressure.

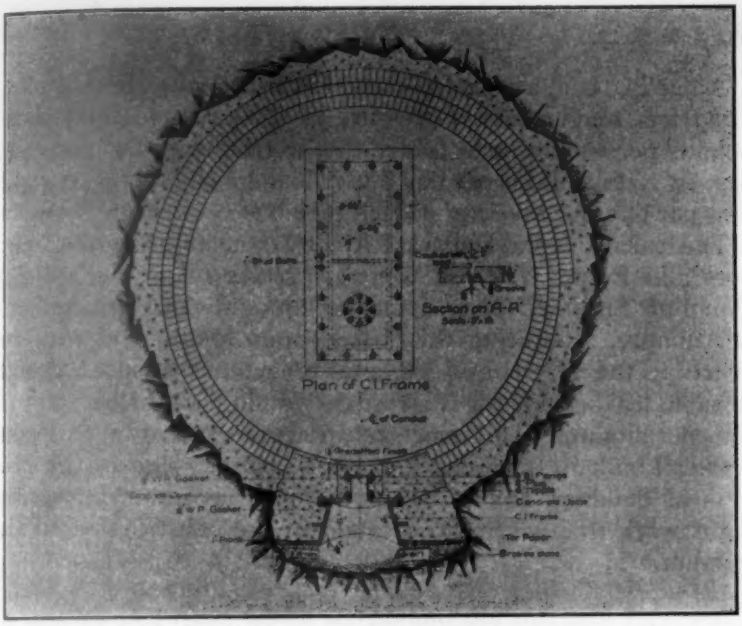

PLATE XXIX.—Method of Closing Sump, Shaft No. 1.

PLATE XXX.—Method of Closing Sump, Shaft No. 2.

A line of 10-inch pipe embraced in the above system of pipe, 3,487 feet long, under a pressure of forty-two to forty-three pounds per square inch, leaked at the rate of 745 gallons per day, or 1,128 gallons per day per mile, equivalent to 5,414 gallons per day per mile for 48-inch pipe.

The leakage of the Delaware River Connections, Gate Chambers and Pump Well, on Contract No. 29, Lardner's Point Pumping Station No. 2, upon test amounted to 15.6 gallons per minute. Reducing this, based upon length and with respects to the very considerable difference in pressures, the allowable leakage for the Torresdale Conduit would be 336 gallons per minute. The structures, however, at Lardner's Point, were all built in open cut, and were kept dry during the process of building, conditions much more favorable for watertight work than were those found in the construction of the conduit.

Proposed Steel Tube Lining.

It has been suggested that the conduit might have been lined with a steel tube instead of bricks laid in cement mortar. In such case probably the steel would have been made up in segments with circular and radial angle iron flanges bolted together on the inside, and the two finished internally with a ring of fine concrete or mixture of cement and sand, say 4½ inches radial thickness.

Such construction would have increased the cost of the work by quite 100 per cent., and the annual interest charge at 3½ per cent. on $1,274,000.00, would have been $44,590.00, or (assuming it to have been possible to make such construction absolutely watertight) about seven times the annual value of the filtered water lost by leakage of the brick-lined conduit.

Refuse from Contract No. 29 Found in Shaft No. 11.

Notwithstanding strict orders were given to the Contractor for Contract No. 29, Lardner's Point Pumping Station No. 2, that no waste materials from his operations while making connection between Shaft No. 11 and Valve Chambers Nos. 2 and 3, should be allowed to go into Shaft No. 11, upon emptying the conduit over thirteen cubic yards of waste material from this contract were found at the foot of the shaft, measuring

about two feet in depth over the center of the invert, and tapering to nothing about fifty feet northward in the conduit. Unless the conduit had been emptied, no one would ever have suspected the presence of this material, which consisted of sand, cement, gravel and similar wastes. The effect of this was to reduce the sectional area of the conduit quite 11.55 square feet, or thirteen per cent. of its least sectional area.

Had this material been allowed to remain in the conduit, its carrying capacity would have been seriously reduced, and instead of charging it to the true cause, viz., that of waste material going into it through operations under another contract, it would probably have been charged to the roughness of the interior or to the insufficiency of the formulas employed for the flow of water through large conduits.

This condition, of course, was a revelation when the first inspection trip was made through the conduit after it was pumped out, and to correct it a hole was cut in Shaft No. 11, a derrick and hand winch set up and the material removed by means of a dumping bucket by hand labor, and the conduit left in a perfectly clean condition.

It is probable that if there had been no question as to the proper completion of the work by the contractor for the Torresdale Conduit (Contract No. 14), and it was known that this material lay at the bottom of Shaft No. 11, excepting it could be removed by the aid of a diver, or by some method of pumping out the material under water, it would have been profitable to have pumped out the conduit solely for the purpose of removing the refuse which came into it from Contract No. 29.

Supposed Ditintegration of Cement.

During the past Summer, while the conduit was being pumped out for the purpose of examination and correction of any omissions or defects which the emptying of the conduit might reveal, it was suggested by a well known chemist in this city that there was some evidence of serious disintegration of the mortar in the brickwork and the concrete. After the conduit was emptied, careful examination was repeatedly made from end to end by myself and several assistants detailed for the purpose, to detect any evidence of disintegration of the

mortar in the joints of the brickwork, and no evidence of injury or impairment from any cause was discovered. While considerable lime was removed with the water from the conduit during the process of pumping out, this, after the first few weeks' pumping, steadily diminished until the water attained about the alkalinity or lime content found by analysis of the water from the shafts and headings previous to the placing of the brick lining and concrete backing. The total amount of lime removed with the water amounted to about 50,000 pounds; and this should be balanced against the lime in 35,000 barrels of Portland cement used in the construction of the work. The cement, under the terms of the contract, weighed about 380 pounds to the barrel, or which, say, 62 per cent. by weight was lime, or 8,246,000 pounds; and of the lime from all known sources, not, of course, including the lime found by test in the rock water previous to lining the conduit, about 0.60 per cent. may have come from the mortar in the joints of the brickwork, and in the concrete.

I am informed by manufacturers of cement that there is a probable one per cent. to one and one-half per cent. excess of lime in the mixture, i. e., the amount of lime is usually slightly more than is really required to make a perfect cement. The influence of this upon either the strength or hardening properties of cement is not noticeable, and if it be assumed that there is a slight excess of lime, it would be possible to lose even a larger percentage than was shown by the estimate of lime lost in pumping out the conduit without impairing the quality of either the concrete or the mortar in the brickwork.

Under the conditions of service it is not thought that the slight outward leakage of filtered Delaware River water will have any serious effect on the lime in the cement, and this opinion is based upon long observation of the influence of water low in lime content, like that of Loch Katrine, on the cement plastering and mortar in the joints of the masonry of the first Glasgow Aqueduct.

ANALYSIS OF WATER FLOWING INTO THE SHAFTS AMD HEADINGS.

During the construction of the work samples of water were collected monthly from the shafts and headings, and analyzed for mineral content and bacteria. The rock water, as would naturally be supposed, excepting for the considerable amount

of iron it carried, was unobjectionable from a sanitary point of view. The bulk of the leakage into the conduit when empty occurred north of Shaft No. 4, or within the first 3,500 feet of tunnel length, at which point, under conditions of service, the pressure of water in the conduit will be greater than the pressure of water in the ground and rock, and the leakage will be of filtered water into the rock and not of rock water into the conduit. The leakage, therefore, does not represent any possible menace to the quality of the water supplied from the Torresdale Filters, but does represent a loss of filtered water, the value of which has been previously noted.

Under conditions of service, with the conduit delivering 300,000,000 gallons per day of twenty-four hours, the lowest elevation which it is expected the hydraulic grade line will take in Shaft No. 11, is 198.00 T. D., or about the maximum elevation heretofore noted of ground water along the line of the work. Of course, when the flow is less than 300,000,000 gallons per day, the hydraulic grade line at Shaft No. 11 will be correspondingly higher, and it would be only at such times as the flow is increased to more than 300,000,000 gallons per day, or for some other reason, the hydraulic grade line might be lowered throughout the length of the conduit, that the elevation of the water in Shaft No. 11 would be below that of the ground water, when a small amount of ground water may find its way into the conduit south of Shaft No. 10. Should this occur, no uneasiness need be felt as to its influence on the very large volume of filtered water flowing through the conduit, and indeed it is doubtful if careful technical tests would show any change in the character of the water at Lardner's Point by reason of the small admixture of water from the rock surrounding the conduit.

In closing this paper I take pleasure in acknowledging the faithful and indefatigable labor of Mr. T. Nelson Spencer, First Assistant Engineer in charge both of the original construction and the examination and repair of the conduit; also, to the work of Mr. Louis R. Snow, Official Photographer of the Department of Public Works, who took the flash-light photographs in the tunnel and the other pictures, and prepared the slides which have been so useful in illustrating construction features of the Torresdale Conduit.

THE PRACTICAL SIDE OF WIRELESS TELEGRAPHY.

A very pretty example of the everyday usefulness of wireless telegraphy turned up the other day when an incoming Cunarder was reported in Boston from a point nearly 800 miles from that port. She was picked up by the Cape Race wireless station and the ordinary wires did the rest. Notice of the probable hour of her arrival in spite of delays which she had experienced was thus given almost two days in advance, to the great convenience of everybody concerned. The same thing will be regularly repeated in all probability, and thus the gap of isolation on the transatlantic voyage will be greatly narrowed. Quite aside from long distance feats, the art of wireless telegraphy can thus be made immensely more useful to mankind than it has yet been. It is not at all necessary to send wireless messages across the Atlantic, for we have the cables already, although active competition with the wireless system would doubtless be some advantage. With the system as we have it to-day, splendid work has been done over distances great enough to be immensely useful, and even if unforseen difficulties block regular transmission half way across the world, we may well be thankful for what we already have. In the Russian-Japanese war the system has shown its immense value in naval operations. The conceptions of a blockading fleet being held at a safe and convenient base until being warned by its scouts that its presence is needed is distinctly worthy of this twentieth century of ours. But the uses of the system in peace will prove still more important, even with greater limitations in distance than are likely to prove permanent. The ocean is no longer an unbroken waste of waters, and by taking advantage of capes and islands the greater part of it can be covered by a wireless system without requiring transmission over more than a few hundred miles in any single stretch.—*Elec. World.*

TREE PLANTING ON THE PENNSYLVANIA RAILROAD.

At the recent convention of the American Forestry Association, in Washington, D. C., Mr. Joseph T. Richards, Chief Engineer of Maintenance of Way of the Pennsylvania Railroad, gave an address on timber cultivation to supply railroads with ties, and the following statements are taken from press reports of that address: Seedlings, two to three years old, cost by the time they are planted, including labor, 8 cents each. They were planted ten feet apart, averaging about 400 to the acre, although 54,871 trees recently were planted 6 feet apart, and 88,127 were set 8 feet apart. The total number planted by the railroad company is as follows: Newton Hamilton, 13,610; Conewago, 68,460; Pomeroy, 20,280; west of Atglen, 16,537; Atglen, 8,108; Juniata Bridge, 20,730; Newport, 29,505; Vintage, 50,3000, and along the Atglen and Susquehanna Branch, 53,000, a total of 280,530 trees. The land, except a tract of 14 acres at Newton Hamilton, is owned by the railroad company. To supply the increasing needs of Pennsylvania alone Mr. Richards estimates that it will be necessary to plant 1,300,000 trees each year for a period of thirty years, the time required for a tree to mature.

ELECTRICAL SECTION

Stated Meeting, held Thursday, February 9, 1905.

The Inspection of Electrical Conductors, With Especial Reference to Fire Protection.

By Washington Devereux,

Electrical Engineer to the Philadelphia Fire Underwriters' Association.

The author, who occupies the responsible position of Electrical Engineer to the Fire Underwriters' Association of Philadelphia, gives, in this paper, a concise statement of the progress and present condition of the science of interior wiring for the protection of buildings from fire from the many sources of danger due to imperfect methods of electric installation.—[The Editor].

Possibly there is no better way to treat the subject before us this evening than to commence at the beginning and with the steps taken to raise the standard of electrical equipments and the introduction in buildings of the same.

At an early stage it was found necessary to regulate the manufacture and introduction of electrical equipments. To the English insurance interests may be attributed the credit of compiling the first code, better known as the "Phœnix Fire Office Rules." The rules were somewhat prohibitive, due to cost of installation of apparatus required. In the early days electric lighting apparatus and materials were far more expensive than at present.

The use of electricity for lighting purposes was a rare novelty, and only for the favored few of great wealth. Electricity for power purposes was unknown.

The insurance interest of America were far more lenient and generous than our British cousins.

Perhaps we were not so well posted in knowledge of the hazard involved and were therefore eager to learn and gain a knowledge to ourselves of that mysterious power of electricity.

We have learned much in the past twenty-five years, and yet how little we know after all. In the light and power world "a little knowledge is dangerous indeed," if the individual thus afflicted ventures too far unassisted.

As a rule the insurance companies pay for the lack of knowledge.

In the past twenty-five years many fires have originated from

defective electric equipment. Many regulations were published by the insurance and electrical interest in an effort to correct previous errors, and while the advancement has been none too rapid in reducing the fire hazard, a marked improvement in the past twenty-five years is most pronounced, and we trust the next decade will enable the engineering world to reduce the hazard of electricity to a minimum.

During the time spoken of opinions as to the best method of installations varied very much among the insurance and electrical interest, and there was strong desire on the part of both to establish a code, which would be acceptable to those most effected.

And while there is quite a difference of opinion regarding some details, on the whole the present regulations are commendable.

To-day we have the National Electrical Code, which is the result of a gradual development originating with the Phœnix Fire Office Rules, having for its primary object the reduction of the fire hazard from electricity, and secondly, a uniform requirement which could be mutually recognized by the insurance and electrical interests, and a basis for the acceptance or rejection of electrical installations.

We do not claim this an ideal code, as experience has shown the necessity for improved equipments. This code is, nevertheless, the expressed opinion of the combined insurance and electrical interests.

A word about the code and its application.

To those who are less familiar with the code the following outline will appeal:—

The General Plan governing the arrangement of the Rules is as follows:—

Under *Class A*, Rules 1 to 11, govern the location, arrangement, construction of material, acceptable in Central Stations; Dynamo, Motor and Storage Battery Rooms; Transformer Sub-stations, etc.

Under *Class B*, Rules 12 to 13, governing outside work, all systems and voltages.

Under *Class C*. Inside work. Rules 14 to 17 govern general requirements, all systems and voltages. Rules 18 to 20 apply to constant current system.

Rules 21 to 23 consists of general requirements for all voltages, constant potential systems.

Rules 24 to 34 apply to Low Constant Potential systems, 550 volts or less.

Rules 35 to 37 apply to High Constant Potential systems, 550 to 3500.

Rules 38 to 39 apply to Extra High Constant Potential systems, over 3500.

Under *Class D,* Rules 40 to 63 apply to the details of construction and materials of fittings, etc., all systems and voltages.

Under *Class E,* Rules 64 to 67 apply to miscellaneous construction, such as signalling systems, electric gas lighting and moving picture machines.

Under *Class F,* Rules 68 to 83 apply to marine work.

It is almost universal in the United States that installations or equipments should comply with the requirements contained in the National Electrical Code, the latter having been adopted by all local Boards of Fire Underwriters.

The development of the code was slow, insomuch as a piece of apparatus or a class of construction was accepted and regulated before its hazard could be determined.

Thus the application of both apparatus and construction has in some cases been confined to narrow limits as the result of experience.

The "National Electrical Code" may thus be said to be the result of broad experience classified.

As we look we are somewhat amazed at the marked difference in the construction and installation of apparatus.

During this period certain features seemed to mark a new era in this particular line, yet in but a short time another feature of equal import was introduced.

The history of the "National Electrical Code" is made up of a series of discoveries which will be dwelt upon this evening.

At an earlier date the importance of wire insulation was not recognized, and bare copper conductors, with a difference of potential from 300 to 500 volts, were stapled to woodwork, and this method of construction was considered good practice. Difficulties were encountered as must be expected, such as electrolytic action, grounds, short circuits and fires, and these

were only limited, due to the fact that very few plants were in operation. It was learned that these difficulties could be reduced to some extent by covering the conductors with insulating material. This led to covering the conductors with cotton paraffined. These insulated conductors were held in place by means of wooden cleats. Such an insulation is highly inflammable, and while some difficulties were eliminated, the fire hazard was greatly increased. This led to the adoption of the "Underwriters" wire. The insulation on this wire consisted of cotton and asbestos fibre, impregnated with white lead. This insulation was fireproof (and was and is to-day most serviceable in hot drying room, boiler houses and places of like nature), but not damp proof, reducing to some extent the fire hazard, but presenting the serious objection, an insulation materially affected by dampness, having a very low, insulation resistance compared with that of cotton paraffined wire.

The wiring contractors make formal application for inspection to the underwriters having jurisdiction. The examinations are made by trained inspectors, whose duties require a strict compliance with the requirements. In the examination points not covered by the code are pointed out and corrected.

This inspection tends to educate those directly or indirectly connected with electrical matters by this transference or interchange of ideas.

New ideas are reserved for future consideration by the National Board of Fire Underwriters, and after acceptance are made a part of the revised code.

Thus the latter is a flexible requirement, changing with the changing of ideas or customs, adjusted to suit these new ideas and costums, but always improving.

In addition to the use of wood cleats for mechanical support, the conductors were laid in V-shaped grooves in wood joist, unprotected except by the wire insulation.

The conductors were subject to mechanical injury and breakage, as the floor boards were sometimes unevenly laid, very often loose, and a constant wear was sustained by the conductors, as the occupants of a building would tread upon the surface wired over. Occasionally joists were bored and the conductors drawn through wooden base switches and open-link wooden cut-outs served as controlling and safety devices in all cases on low potential system, 110 to 220 volts.

The weakness of the above methods were soon noticed and eliminated to this extent, the conductors were no longer laid in V-shaped grooves, and the holes in joists through which conductors passed, were bushed with soft rubber tubing. This insulation proved a failure. Then followed the hard rubber tube; failure again. Papier maché tube treated with several coats of asphaltum, then papier maché sheathed with brass. All in turn were failures, lacking qualities desired and necessary solder was at a premium, judging from the number of unsoldered joints. Tin foil was often used as a substitute, principally with a view of deceiving the inspector.

The necessity for support of higher insulating qualities developed the porcelain knob and cleat. The application of glass and porclain to the manufacture of insulators and of porcelain to the manufacture of cut-outs and switch bases was a marked stride in the development of higher quality of electrical fittings.

The "Underwriters,'" or composition asbestos wire, had in it the weak feature that it was readily affected by moisture. This wire was later covered with a cotton or hemp braiding coated with asphaltum, pitch and tar, or a composition simliar to Chatterdon compound, making a comparatively good insulation. While fresh this insulation will burn readily, but when thoroughly dried out is of slower combustion, and is commercially known as "Slow-Burning," sometimes "Fire and Weatherproof." The latter title, however, is erroneous and misleading.

The necessity for an insulation having a higher value than "Underwriters'" and "Slow-Burning" insulations was apparent and lead to the construction of rubber-covered wire. This was followed with a rubber-covered wire having a single outer wrapping of tape. Two weaknesses were noted. First, the copper wire was chemically affected by the sulphur mixed in with the rubber, and second, the outer covering dried up, unwrapping or otherwise exposing the inner insulation to a varying atmosphere, eventually drying and cracking the rubber. The first trouble was remedied by tining the wire, the second by applying a braid of one, two or three layers.

From the number of layers of braid we name the wire, for instance the triple braid having in addition to the rubber insulation, three distinct braids of insulating material.

Undoubtedly the braid greatly enhanced the insulating value of rubber covered wire.

We have briefly scanned the field, from the use of bare wire stapled to the rubber-coverd wires, mechanically supported by knobs and tubes.

This is indeed a great improvement and it will no doubt surprise you to note a backward step.

Knob construction was found objectionable from an artistic standpoint, also because the wiring in many instances was subject to mechanical injury. The circuits thus disarranged coming in contact with gas pipes, water and steam pipes, causing grounds, leaks in multiple, and many times creating a fire of more or less magnitude. Thus the need for some device that would entirely conceal the wire, brought forward the "Astrakan" moulding.

This moulding was made of hard wood, grooved in the back. The wires were laid in the grooves and nailed anywhere. This class of construction was not without fault and its adoption was indeed a backward step.

The rubber wire very often resting against new plastered walls and ceilings was acted upon by the chemical limes, etc., rapidly deteriorating the insulation and creating a fire.

The "Astrakan" moulding was soon replaced with the present two-piece moulding, though of lighter construction and untreated with a moisture repallant and the same disastrous results followed, as in the adoption of the "Astrakan" moulding, to a lesser degree, however.

The present moulding is of heavier construction, thoroughly treated with two and sometimes three coats of moisture proof paint and has proven fairly satisfactory. Care, however, is needful never to install moulding work in wet places or where the possible overflow of a tank, sink or accidental breaking of a water pipe may saturate the moulding and thus cause a fire.

Attention was given to the development of some form of insulation between gas fixtures and the house piping. Insulting joint having soft rubber insulation was adopted, but failed owing to the chemical changes in the rubber and its mechanical weakness.

The principal weakness, however, was the extreme inflammability of the rubber. "Bug" cut-outs were invariably placed

in the canopies of fixtures. The melting of a fuse many times would flash sufficiently to ignite the soft rubber which quickly communicated with the illuminating gas contained in the house piping, creating a fire close to the ceiling. Sometimes side brackets were thus effected, located on hollow frame partitions. The fires were not easily controlled, as it was always necessary to turn the gas supply off at the meter. Before this could be accomplished a fire of no small proportion sometimes occurred.

The soft rubber joint after a few years proving unsatisfactory and unsafe, was replaced by the hard fibre joint and finally the mica insulating joint, while not indestructable, when subjected to an electric arc has proven more satisfactory than any insulating joint yet produced.

The introduction of the mica insulating joint greatly reduced one of the most serious weaknesses in an electrical installation.

If we will but consider that the combination gas and electric fixture contained two factors, having dangerous characteristics if improperly handled, one being able to puncture the gas pipe and the gas ignited by the consequent spark (arc), we more readily appreciate the real value of the insulating joint. The possibility of grounds to earth on fixtures attached to gas piping has been reduced by the use of the mica insulating joint. It was also required to cover the wires at the outlet to avoid possible contact with the house piping. This was accomplished by covering the wires with soft rubber tubing, a poor remedy. Later the improved means of flexible, slow burning tubing, and finally procelain tubes.

"It is also recommended that the gas outlet pipe be protected above the insulating joint by approved insulating tubing, having a flange at the lower end where it comes in contact with the insulating joint." The use of electric gas lighting on the same fixture with electric lighting is most inadvisable, as the insulating joint is rendered practically worthless by the gas lighting wires bridging the insulating joint. In fact, straight gas or straight electric is the best practice.

Probably no portion of the electrical equipment, with one exception, is more roughly handled than the sockets and the

introduction of the lined socket was a marked improvement indeed.

The great need of a wireway or raceway for electrical conductors was most apparent. A method system, if you please, whereby the electrical conductors could be more systematically installed and at the same time practically accessible at all times. The desire to better general conditions brought forth the "Interior Conduit System," which consisted of tubes of papier mache, treated with several coats of asphaltum, an excellent insulating compositon, but very inflammable. Iron outlet and junction boxes into which the tubing and open link cut-outs nicely fitted, completed the system and was pronounced by many as ideal. The owners of these patents and stockholders reaped large financial gains.

The serious objection to this system was its freedom to mechanical injury and its inflammable qualities. The applying of an outer thin brass covering, forming what is known as "Brass Armored Tubing," did not remedy the difficulty, as the brass was readily punctured, adding an additional defect in the form of a sharp projection, very often cutting the insulation and increasing the fire hazard.

The great problem is how to secure safety, and this may be answered: By the proper method of construction, using only high grade material.

The fire hazard should be always carefully considered in an electrical installation, and the National Electrical Code carefully applied. In applying the code care must be taken in the proper discrimination of the hazard and to apply that electrical system which will be less apt to increase the hazard. The equipment should be installed by skilled wiremen, guided by experienced engineers.

Evidences of the lack of knowledge on electrical subjects are quite apparent; nails and screws driven into electric light and power moulding, wires in contact with gas pipes, water pipes, water tanks, metal awnings, metal ceilings, iron beams, cornices, awning frames and metal signs. The introduction of various auxiliary devices for varying the candle power of lamps, lamps in series with bell and telephone systems and connected to lighting systems, and other similar makeshifts, are in the wrong direction, increasing the fire hazard, not neces-

sarily because of faulty construction, but because their constant manipulation is in the hands of those less informed or absolutely ignorant of the danger involved.

In the manufacture and distribution of electrical energy there is a loss by heating due to the fact that all substances have a resistance which has to be overcome and which represents a loss in energy, which is substantially all transformed into heat. The heat which is produced in a wire only depends on the number of watts expended electrically by the current in overcoming the resistance of the wire, which resistance varies with different materials, and goes to raising the temperature of the conductor and indirectly that of the surrounding bodies; and this rise continues until the rate at which heat is lost equals that at which it is generated; then the temperature becomes constant. It is obvious, therefore, that an electrical conductor is only capable of carrying a certain current with a given elevation of temperature, and, practically the allowable temperature is limited by consideration of injury to insulation and the danger of fire.

The lined iron conduit was next introduced. The conduit was of iron, having the general characteristics of gas pipe as tc size and quality and was bushed throughout its entire length with a treated wood else papier maché lining.

This class of tubing presents numerous objections. The most serious is perhaps its liability to fracture the insulation of conductors during the process of "drawing in," the wood lining often giving way, forming sharp projections and puncturing the conductors.

This tube was soon followed by a galvanized iron pipe, similar to gas pipe, but galvanized to prevent corrosion.

The iron conduit is an inflexible system, and the demand for a system of piping having all the properties of iron conduit with additional flexibility, led to the "Flexible Iron" conduit system.

The outline here shown of the improvements in methods of construction are only the more important.

The step from uninsulated wire stapled to double braided rubber covered wire in metal conduit is a big one, covering more than twenty-four years of slow and steady care in selection.

The insurance inspector has played no small part in these improvements. His experience with the various classes of apparatus or of construction has sifted out the bad features and only the most improved appliances and fittings withstand his criticism.

After years of experience, of tug and tussle, of acceptance and rejection, has resulted in the present National Electric Code.

The temperature elevation of a wire for a given current strength depends upon its resistance, diameter, covering, and its surroundings. A copper wire carefully insulated by a thin coating of water-proof material and placed in still water is usually kept comparatively cool, owing to the rapid conduction of heat through the insulated cover into the water.

The same wire, carrying the same current, but suspended in air instead of being immersed in water, will usually attain a considerably higher temperature, as still air does not carry away heat from the surface of the wire so effectively as still water. For the same reason a wire buried in the ground will, in almost all cases, be found to be cooler than where supported in the air. A covering of, say, cotton, rubber, or other electrical non-conductor will, up to a certain thickness, serve to cool the wire by increasing its surface.

The same heating conditions would apply to switches, switch or fuse lugs, bus-bars, commutators, and in fact to any current-carrying parts of a circuit, and it is therefore necessary that they be sufficiently heavy to carry the required current without undue heating.

Heating may be the result of insufficient contact surface, and the tendency in all cases is to increase the temperature to a dangerous point, or to melt and ignite the insulation of an inflammable nature, such as rubber and cotton. It is necessary, therefore, that the carrying capacity of current-carrying parts and of contacts shall be limited.

Poor connections at fuse blocks may produce heat enough to cause the fuse to melt when there is really no trouble elsewhere on the circuit. This may occur when the fuse blocks have too little contact surface at the connection points to properly carry the current, or when the contact surface is not se-

cure, in which case arcing occurs, pitting the surfaces and intensifying poor contact.

The formation of an arc may be understood by the following explanation: The two conducting terminals under ordinary circumstances are brought together before being separated to establish the arc. As soon as this separation commences, the spark which tends to form at any break in a closed circuit vaporizes a portion of the materials of the electrodes, thus establishing a bridge of conducting vapor through which the current flow is maintained. The concentration of energy in a small space produces an intense heat, which vaporizes the electrodes more rapidly. The temperature of this arc, although difficult to determine accurately, is about 3500° C. We may obtain an approximate idea of this heat when we consider that about 500° C. are necessary to make solid bodies glow with light, and that the melting point of platinum is 1775° C.

As was noted previously, the presence of two leaks on an electrical circuit, creating an electrolytic action and finally a break in a circuit, is attended with the destructive arc. It is equally true that the breaking of any circuit, whether it be by means of a properly proportioned switch, the melting of a fuse, or the breaking of a current-carrying wire, is attended with this arc. Where the numerous blowings of fuses have occurred, the porcelain surface of the fuse block is often covered with a layer of metallic substance, which becomes a partial conductor. Upon the repetition of this blowing, an arc is formed and maintained by this metallic layer; in many cases the porcelain cover is fused and broken.

In other cases, particularly slate switch and distributing boards, the melting and resulting arcing have been known to crack the insulating substance and the various conductors short-circuited. In other cases the short-circuiting of an incandescent lamp has destroyed the sockets or controlling devices beyond repair. The throwing out of sparks from arc lamps and the dropping of hot carbons have been known to cause fire. Sparks from the commutator to motors, from the short-circuiting of flexible cords and of fixture wires, from the short-circuiting of cables in conduits and in manholes, igniting accumulated gases; from short-circuits in sockets, attachment

plugs, receptacles, switches and various other devises have been known to cause fire.

Overheating of wires, of motors, dynamos and switchboards from overloads; overheating of starting boxes; overheating of theatre dimmers and regulating boxes from overload; overheating of improperly made joints, which may be considered the weakest part of an installation, and may include joints between wires, between wires and lugs, between lugs and busbars, or between switch blades and clips; overheating of magnet coils or resistance of arc lamps, and innumerable other similar defects have been known to create a fire.

Other sources of fire may be the contact of an incandescent lamp with inflammable material, such as cotton, paper, wood, celluloid goods, etc.; the melting of fuses, the breaking down of insulation, sparking from electrolysis, or short-circuits in places impregnated with inflammable gases, such as benzine, naphtha, ether, hydrogen, gasolene, and many others of explosive nature; also in any class of manufacture where vegetable material is distributed through the atmosphere in the form of dust, extra precautions are absolutely necessary, the least flash or arc being sufficient to cause an explosion.

Candy factories, sugar refineries, flour mills, breweries, saw mills and others of like hazardous nature may be considered in this category; also textile mills, where there is an accumulation of the particles of stock that is carded out, which particles, owing to their extreme lightness, fill the air in the rooms, and, settling, completely cover everything with an inflammable material usually known as "fly," which is a fine dust of vegetable matter. In this condition the dust may be ignited by the blowing of a fuse or similar accident.

It will be noted from the remarks made in this paper that electricity is treated as a source of heat and as such is classed as a fire hazard, and it is fair to say that it presents to us a most dangerous and powerful factor in that respect, if an equipment is improperly installed, abused, or permitted to be neglected.

That electrical equipments are abused and neglected is a fact too well established to permit of argument.

This is particulary true of isolated plants.

There is no class of industry which should receive greater

consideration than the interior wiring of buildings for light and power purposes.

A word to the public:—Engage only reputable electrical contractors and engineers, who in turn may be presumed to employ artisans skilled in their calling; and, as a further precaution do not pay a bill for additions, alterations or repairs to any portion of an electrical equipment until a certificate of approval has been furnished by the Board of Fire Underwriters having jurisdiction, or other properly constituted authorities.

In referring to the fire hazard of electrictiy, we must not lose sight of the fact of the great benefits which this subtile force has bestowed upon mankind.

Electricity will cause fire under certain conditions; the same agent, regardless of the cause of fire, is used in sending out the fire alarm, affording quick and ready relief. This may be accomplished by the police and fire alarm systems, else the automatic alarm, a silent monitor and a watchman, who never sleeps. By the same power the electric fire pump automatically supplies water in abundance to the fire mains, stand pipes and automatic sprinkler systems, thus rendering great assistance to the fire department in the execution of their duty.

By the aid of electricity we can send by telephone or telegraph messages to all civilized parts of the earth.

Civilization is crude indeed if electricity has not made its impress upon the surroundings.

Humanity has greatly benefited by the use of the Finsen and the X-Ray.

Electro-therapeutics to-day is indispensible to the medical and surgical world. In fact to enumerate the innumerable great and lasting benefits which electricity has afforded humanity is a task beyond the ability of any man.

After due consideration of the fire hazard involved, we must admit, if properly installed and not abused, electricity is the safest source of light which the ingenuity of man has produced, and its fire record is far below the oil record and its casualties are nil when compared with oil lamp statistics.

"Platinoid," mainly a nickle-copper allow, owes to the presence of a little tungsten its peculiar property of having a higher electrical resistance, which does not change with temperature.

CHEAP STEAM PRODUCTION.

A letter to the editor of *Engineering* (London), printed in a recent issue of that periodical, was evoked by an earlier letter asking whether the cost of 2 shillings 4 pence (56½ cents) for evaporating 1000 gallons of water can be beaten. The writer sends particulars of a test made at James Oakes & Co.'s Riddings Colliers, near Alfreton, England, on April 19 of last year. The plant consisted of a Lancashire boiler fitted with two patent hot-air furnaces, supplied by the Hot-Air Furnace Company, Birmingham, England, and one of its downtake superheaters. The following are the data given:

Size of boiler	8 feet diameter by 30 feet long
Average boiler pressure	80 pounds
Temperature of saturated steam	324 degrees F.
Temperature of superheated steam	540 degrees F.
Degrees of superheat	216 degrees F.
Temperature of feed water entering economizer	90 degrees F.
Temperature of feed water entering boiler	250 degrees F.
Temperature of gases entering economizer	540 degrees F.
Temperature of gases entering chimney	230 degrees F.
Pounds of water evaporated per hour (actual)	9,768
Pounds of water evaporated and superheated per pound of coal (actual)	9.5
Equivalent evaporation of saturated steam from and at 212 degrees pound of water per pound of coal	12.2
Class of fuel	Dirty slack
Cost of fuel per ton at colliery	48½ cents
Actual cost of fuel to generate and to add 216 degrees F. of superheat to 1,000 pounds of steam	2¼ cents
Equivalent cost of fuel to generate 1,000 pounds of steam from and at 212 degrees	1¾ cents

This shows that the actual cost of the fuel to generate the steam from 1000 gallons of water and superheating it 216 degrees is but 11¼ pence (22½ cents), as compared with 1 shilling 11 pence (about 46 cents) for the generaling of steam in the boiler previously referred to.

TESTING OF WIRELESS TELEGRAPH SYSTEMS.

It is understood that the various systems of wireless telegraphy now in use are to be tested in the annual naval maneuvers in the Caribbean Sea. Plans are being made for elaborate tests, and a majority of the vessels participating will be equipped with the wireless apparatus. Two or three different systems will be used and every effort will be made to intercept wireless messages and to break the lines of transmission. The vessels of the squadron will, as far as possible be controlled by wireless telegraphy from the beginning of the maneuvers until the fleet comes north to Pansacola in March for target practice. Every effort will be made to test the efficiency of the instruments now used by the government.

Section of Photography and Microscopy

A Solid Invisible Bifocal Lens.

Stated Meeting, held Thursday, January 5th, 1905.

By J. L. Borsch, M. D.

In this paper is described the evolution of the bifocal spectacle lens, leading up to a substantia improvement devised by the author, in which the objections to the present composite bifocal lens are avoided by the successful construction of a solid invisible bifocal glass.—[The Editor].

When asked by your President to read a paper here I could not help remarking how appropriate a place is the Franklin Institute to present a paper entitled "A New Bifocal Lens," since it is to the distinguished statesman and inventor for whom this institution was named that we owe the invention of Bifocal Lenses.

Their history is interesting, in that it portrays quite vividly the fact that one often tries many complicated means to accomplish a thing which can be done very simply—when one knows how to do it.

It is my purpose to state briefly the conditions of the eye in which these lenses are used, to review their evolution and to say a few words regarding the new lenses.

With your kind indulgence a few facts in Physiological Optics will be recalled in order that all may better understand the use of Bifocals, or glasses with which one can see both near and far.

The principal optical defects are due, 1st, to an anomaly of curvature of the cornea or the crystalline lens, or 2nd, to an abnormal composition or condition of one of the refractive media of the eye. They both cause practically the same symptoms; but most optical defects are due to an anomaly of curvature.

The cornea is that membrane which is to the eye what the crystal is to the watch, and must be of equal curvature in all meridians and perfectly transparent, so that parallel rays of light striking its surface will pass through it and come to a focus on the macula or most sensitive spot of the retina, which membrane is to the eye what the sensitive plate is to the camera. The retina is the expansion of the optic nerve in the eye and conveys to the brain the impression of the image received upon it.

The crystalline lens is a gelatinous substance enclosed in a

capsule or sac suspended in the eye just behind the pupil and controlled by a circular muscle called the ciliary muscle. Its form can be made voluntarily more or less convex so that both

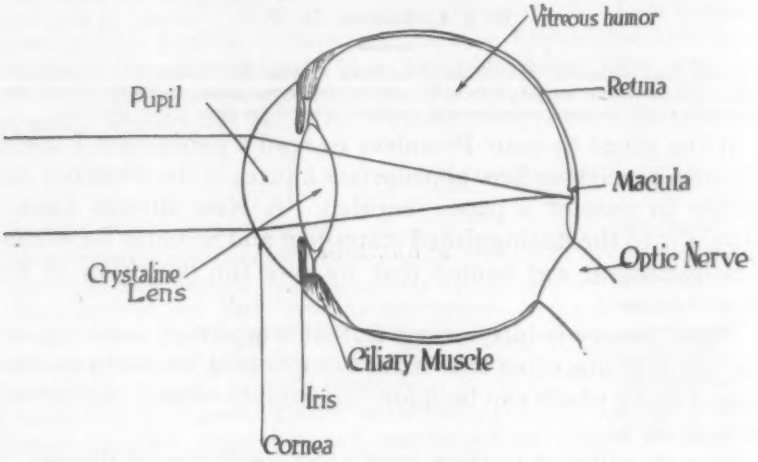

Fig. 1. Emmetropic, or normal eye.

near and distant objects can be focused alternately on the retina and thus be distinctly perceived. This adaptation of the crystalline lens is what is called Accommodation.

Now, when the cornea is of the proper curvature and transpa-

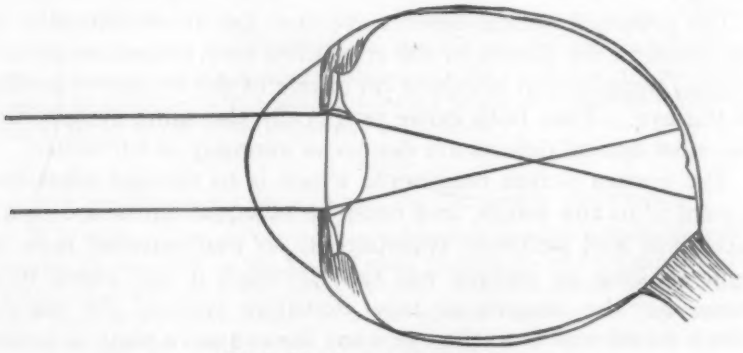

Fig. 2. Myopic, or nearsighted eye.

rent, the crystalline lens in a normal condition and the eye otherwise healthy, parallel rays of light entering such an eye will come to an exact focus on the retina, and the person will

see objects distinctly without the aid of glasses. This condition of the eye is known as Emmetropia, or normal sight.

When the cornea is of too great a curvature, the eye-ball too long, or the crystalline lens too convex, parallel rays entering such an eye come to a focus before they reach the retina, and consequently make an indistinct picture upon it. Such a condition is known as Myopia, or near-sightedness, and is corrected by having the person wear near-sighted or concave spherical lenses.

When the cornea is of insufficient curvature, the eye-ball too short, or the crystalline lens too flat, parallel rays entering such an eye would come to a focus behind the retina and again cause an indistinct image to form upon it. This condition of

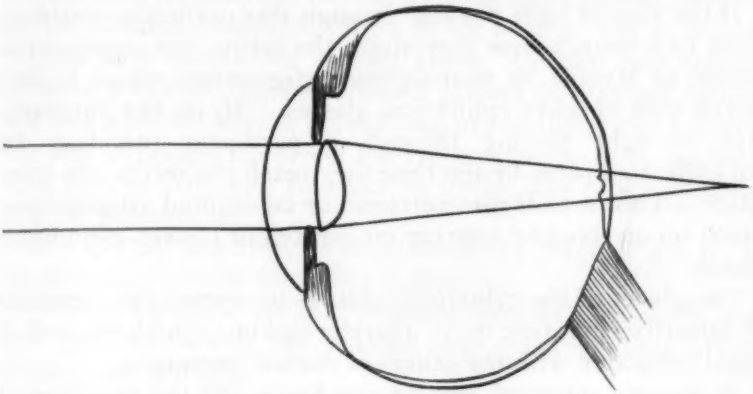

Fig. 3. Hypermetropic, or farsighted eye.

the eye is known as Hypermetropia, or far-sightedness, and is corrected by the use of convex spherical lenses.

When the curvature of the cornea or the crystalline lens is greater in one meridian than in the others (or above the normal curvature), parallel rays entering such an eye do not all come to a same common focus on the retina. The rays of light passing through this greater meridian, will come to a focur in front of the retina, while those going through the other meridians will come to a focus on the retina; therefore, that part of the retina upon which fall the rays that have passed through the meridian of greatest curvature will perceive an indistinct image while the other part of the retina upon which the normal rays

fall will perceive a distinct one. The image as a whole, however, will be an indistinct one. This condition of the eye is known as Astigmatism.

To learn whether the cornea or crystalline lens is of equal curvature and refraction in all meridians, the patient is asked to look at a chart consisting of circular discs made up of black parallel lines of equal intensity running in different directions, such as was devised by Dr. Paul Sartain, of Philadelphia, some five years ago, and lately published as something entirely new by a foreign authority.

If any disc appears more distinct than the others it indicates that the curvature of the cornea or the crystalline lens in the corresponding meridian is different from that of the other meridians.

If the rays of light passing through this particular meridian come to a focus before they strike the retina, the condition is known as Myopic, or near-sighted astigmatism, which is corrected with concave cylindrical glasses. If, on the contrary, rays of light passing through a particular meridian do not come to a focus by the time they reach the retina, the condition is known as Hypermetropic, or far-sighted astigmatism, which is corrected by wearing far-sighted or convex cylindrical lenses.

The object of the cylindrical glass is to correct the meridian of defective curvature only; thereby making it uniform and of equal refraction with the others of normal curvature.

A concave spherical lens, as you know, has the property of causing parallel rays of light passing through it to become equally divergent in all meridians, while a convex spherical lens has the property of causing parallel rays passing through it to become equally convergent and unite at a single point called the focus. The focus of a convex lens is behind the lens while that of a concave lens is in front. A cylindrical lens differs from a spherical one in that the cylinder has only one meridian of greatest refraction while the meridian at right angles to it is neutral. This meridian is called the axis and is so placed before the eye as to coincide with the meridian refracting rays of light normally.

A good comparison for a cylindrical and spherical lens is one Dr. Paul Sartain proposes, which is, that "a cylinder corre-

spond to a section cut from the side of a stovepipe, and a spherical lens to a section from a ball."

Many persons have both myopia, or hypermetropia, and astigmatism in the same eye. For example, a person who is near-sighted and wears spherical lenses to correct his myopia, can acquire an astigmatism in addition to his myopia. A combined spherical and cylindrical lens is required to correct this condition, known as compound astigmatism. Such a lens is called a compound cylinder, because it combines both a spherical surface and a cylindrical one; one side of the glass being ground with a spherical and the other with a cylindrical curve.

A far-sighted or astigmatic person below the age of 40 years can see both far and near objects with the same glasses, because he has sufficient accommodation to see near as well as distant objects with his distant glasses alone. Certain near-sighted persons, however, require different glasses to see near and far just like a person having presbyopia, or old-sight, who requires one pair of glasses to correct his hypermetropia, or far-sightedness, and an extra pair to make up for his loss of accommodation, or presbyopia.

It is to that vast army of those requiring different glasses to see near and far that bifocals are designed.

There is a popular belief that bifocal glasses necessarily indicate that the wearer has reached that great bugbear of the human race, old age.

This is not a just belief, but is founded on the fact that many persons past middle life wear them to avoid the annoyance of two pairs of glasses. Now, in really anyone, no matter of what age, who is moderately near-sighted and astigmatic, for example, and consequently of weak accommodative power, unless he wishes to be burdened with two pair of glasses, must wear bifocals in order to see both near and distant objects distinctly.

Another popular belief is that a person should put off wearing glasses as long as possible, as they are said to ruin the eyes, and that when one becomes accustomed to them it is impossible to see without their aid. This, of course, is an error, as a glass simply deflects the rays of light before they enter the eye that they may come to a focus at the proper point on the retina.

It is no more harmful to the eye to wear properly selected and fitting glasses than it is for a man to stand on a step or elevation in order to see something beyond the range of his height.

As to the inability of the wearer to dispense with glasses when once he becomes accustomed to them, it should be said that no harm can result from glasses that have been properly seleted by a competent oculist, and made and fitted by a first-class optician; and, if one cannot get along without them once they have been worn, it means that the glasses have opened the wearer's eyes.

Again, many people are indifferent as to how they treat their eyes, and wear glasses that others have no further use for, not stopping to consider whether the glasses will do harm or not. I have known ladies who wore lorgnettes which belonged to their mothers or aunts, or glasses that had been worn by their brothers or sisters, yet these same ladies would become highly indignant if asked to wear their brothers' or sisters' cast-off hats or shoes.

About the worst case of abuse of the eyes within my knowledge was that of a boy who was taken to an oculist for treatment of his greatly inflamed eyes. Upon inquiring of the father how the boy had acquired this inflammation, he responded that his son had weak eyes, but as he objected to having him wear glasses some neighbor advised him, and here I quote his words: "To spit tobacco juice in the boy's eyes to strengthen them," which advice he had followed. When admonished for this, his wife, by way of reassurance said, "But, Doctor, my husband used the best tobacco he could get."

FRANKLIN—1777

SCHNAITMAN—1826

To return to bifocals, it may here be said that were first used by Dr. Franklin, who, while Minister to France, in 1777, had Secretan, a Parisian optician, make them for him. He was greatly pleased with his invention, and

wrote that they helped him to win many arguments and thus accomplish his mission, which was to get the assistance of France in our struggle for independence, in which, as we all know, he succeeded. In one of his letters he wrote that when he wore these glasses he understood French much better.

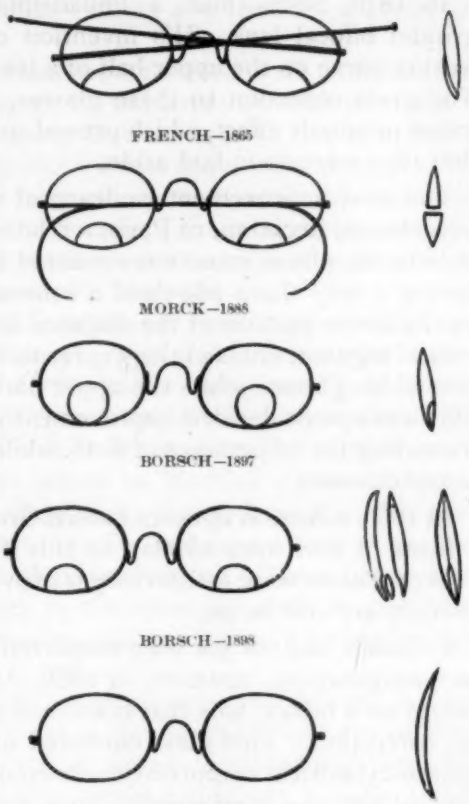

Fig. 4. Evolution of the bifocal lens

The fact is that Franklin was very far-sighted, both mentally and optically, and while his mental hypermetropia permitted him to see far into the future, his sight did not permit him to see the expressions of French faces distinctly; with his bifocal glasses he could "see" what his French friends said, hence the above remark. He not only deserves the credit for their invention, but also that of having popularized them, for soon after many wore Franklin glasses, by which name they are still known.

For some years "Franklin" or "Split" bifocals were the only ones used, and some are still in use in France to-day.

The objection to these lenses is that the line of junction between the near and far glass is very annoying; persons while wearing them have great difficulty in walking, owing to the prismatic effect which is due to their construction; the wearers of bifocals of to-day, especially the feminine ones, are unkind enough to term Franklin glasses "unsightly."

In 1836, Schnaitman, a Philadelphia optician, invented a ground bifocal lens. His invention consisted of grinding a weaker curve on the upper half of a lens of stronger curvature. The great objection to these glasses, however, was their extreme prismatic effect, which proved so annoying to the wearer that they were soon laid aside.

The next improvement we learn of was made in 1865, by a Frenchman, Secretan, of Paris, a relative of the original maker of bifocals, whose invention consisted in cementing a segment having a very sharp edge and a somewhat semi-circular form, on the lower portion of the distance lens. This small supplemental segment enabled the wearer to read with the lower portion of his glasses, while the upper part was for distant vision. This was a most decided improvement on the preceding forms, presenting the advantages of both, while avoiding many of their inconveniences.

In 1866, a Boston optician named Gregg, secured a patent on a form of lens very similar to this French one; that these French glasses were satisfactory is proven by the fact that some of them are still in use.

Cylinders had not yet been employed in bifocal lenses to correct astigmatism; however, in 1888, August Morck secured a patent on a bifocal lens that combined a cylindrical and spherical correction. This glass consisted of a distance lens of the sphero-cylindrical conformation desired; the lower portion was ground out in a semi-circular form and a segment of the appropriate reading combination was inserted in the place of the section removed. The two glasses were so adapted that the line of separation was least perceptible and had the distinct advantage of being exactly centered; that is, the optical center of each lens coincided with the geometric center of the corresponding lens. This lens fell into disuse when the French bifocals were made with sphero-cylindrical combinations.

Bifocals then reached so high a standard that oculists and opticians thought they had a lens which would forever remain an example of perfection. They had overcome the prismatic effect of the Schnaitman lens, the line of junction of the Franklin, and the prismatic effect of the Gregg glass, and thought the patient would forever now be content, but they had reckoned

without two powerful hosts—vanity and sensitive nervous systems.

In effect, the lens that had come to be so much admired by all was gradually looked upon, by the ladies especially, as not so near perfection as it was at first thought to be; that line of junction of the near segment with its knife edge was not so imperceptible after all; in fact, when one knew it was there and had seen it a few times, it became quite noticeable; but what sealed its fate and made it an eyesore was the remark of some people, that it made the wearer look old.

In 1897, Borsch, of Philadelphia, devised a glass, which was termed the depressed bifocal. To make this lens he took a piece of Crown glass of certain index and ground it according to the required distance correction; in the lower part of this glass a circular or semi-circular depression of 17 millimeters in diameter was made into which he inserted a lens of higher index of refraction according to the strength required for near. The lenses were cemented together and gave a bifocal, the surface of which was but slightly interrupted. These lenses were further improved in 1898, by the same inventor, by enclosing the small segment between two plates of glass forming the distance correction.

The latter are very neat in appearance and delicate in construction, and combine most of the desirable features of bifocals; they are, however, in three pieces, cemented together with Canada balsam which, under certain conditions, is liable to become loose and clouded; then again, these lenses are quite expensive, so that they are within the reach of a limited number of persons only.

For a number of years the author has been endeavoring to devise a lens which would embody all the desirable features of a bifocal, from the oculist's, the optician's and the wearer's point of view. These desirable features are as follows: a bifocal having no perceptible line of junction between the near and far portions of the lens, no prismatic displacement, no cement to become loose or cloudy, a lens having the optical and geometric centers for the near and distance correction corresponding with each other, and, what is of no little importance, one that can be made by any lens grinder and at so modest a cost that it may be within the means of anyone requiring bifocals to gain a

livelihood; and lastly, a bifocal that won't make the wearer look old.

This has been successfully accomplished, and the lens is made in the following manner: A depression is made in a piece of ordinary optical glass of refractive index of 1.53, and into this depression is placed a glass of higher refractive index, varying according to the strength of the lens required. These two glasses are placed in a special muffle, through which a current of electricity is made to pass, which causes the two glasses to coalesce or melt together without altering the indices of refraction of the component substances. This new piece of glass is taken from the muffle and given to the grinder, who grinds the required focus according to the distance prescription. The difference in density of the two glasses used will give the required near focus without any further grinding.

show you the result of these several years of work by exhibiting to you the solid invisible bifocal lens.

Book Notices.

The Telescope. Optical principles involved in the construction of refracting and reflecting telescopes, with a new chapter on the evolution of the modern telescope and a bibliography to date. By Thomas Nolan, M.S., A.M. (2d Edition, revised and enlarged, 16 mo., pp. 128.) New York: D. Van Nostrand Co. 1904. (Price, 50 cents.)

This volume forms one of the well known "Van Nastrand Science Series." The author has brought his subject up-to-date by adding a new chapter describing briefly the advances made since 1880, when the first edition appeared, and including a useful bibilography. W.

American Compound Locomotives. A practical explanation of the construction, operation and care of the compound locomotives in use on American railroads. By Fred H. Colvin. (8 vo., pp. 143.) The Derry-Collard Company, New York; The Locomotive Publishing Co. Ltd., London. (Price, $1.00.)

The railway engineers and the locomotive builders will find Mr. Calvin's work an exceedingly useful compendium of information pertaining to the compound locomotive as developed for use on American railways. W.

American Meter Practice. By Lyman C. Reed. 8vo, pp. 196. New York: McGraw Publishing Co. (Price, $2.00.)

The railway engineers and the locomotive builders will find Mr. Colvin's output of central electric power stations, and the electrical engineer will find it most useful should he have occasion to need a selection of the commercial meters, or to compare them in respect of efficiency and accuracy. W.

Franklin Institute.

[*Proceedings of the Stated Meeting held Wednesday, March 15, 1905.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 15, 1905.

PRESIDENT JOHN BIRKINBINE in the chair.

Present eighty-four members and visitors. Additions to membership since last report, twelve.

Prof. Lewis M. Haupt read a communication on "Tunnel Engineering with especial reference to the Simplon Tunnel." The paper was a brief historical sketch of the advances made in this branch of engineering by the introduction of improved drilling tools and high explosives.

Mr. Byron E. Eldred, of New York, was introduced by the Chairman, and gave an informal account of his "Method of Regulating Temperatures."

Mr. H. I. English, representing the Gray Telantograph Co., gave an account of the evolution of the telautograph since its first introduction in 1893.

These communications were freely discussed and were referred for publication.

The subjects of the remarks of Messrs. Eldred and English were referred to the Committee on Science and the Arts for investigation and report.

The Chairman extended the thanks of the meeting to the speakers of the evening and the session was adjourned.

WM. H. WAHL,
Secretary.

Committee on Science and the Arts.

(Abstract of Proceedings of the Stated Meeting held Wednesday, March 1, 1905.)

DR. E. GOLDSMITH in the chair.

The following reports were adopted:

(No. 2310.) *Contributions to the Study of Documents, and Especially a Method of Quantitative Colorimetry.* Dr. Persifor Frazer, Philadelphia.

ABSTRACT: The contributions of applicant to the scientific study of documents, the determination of the individual character of handwriting and the detection of fraud and forgery, including in particular the wedge-shaped color prisms devised by applicant for aiding in the work of examining inks constitue the subject of this investigation. These contributions are contained in a published treatise of Dr. Frazer on this subject termed, "Bibliotics, or the Study of Documents," which the members of the sub-committee have examined, and express themselves satisfied that it is a clear, comprehensive and masterly exposition of this difficult subject, and a work of high scientific and literary merit.

The Sub-committee has also examined and tested the device of the color prisms submitted by applicant. These consist of gently-tapering wedges of tinted glass, which are placed over the writing, in a strong light and moved across it from the thinnest to the thickest end. While so doing there will occur two critical points; the first, that at which the ink marks appear of maximum darkness relatively to the background against which they are

contrasted; the second is that at which the ink marks are no longer recognizable against the background; that is, they disappear.

The observation of one or both of these points, measuring carefully the distance from the point of the wedge at which they occur, gives data characteristic of the relative intensity of the ink mark tested.

In the opinion of the sub-committee, these prisms in the hands of one skilled in using them, are capable of giving approximate quantitative values to the relative color values of ink, and that the results of their use are of valuable assistance in the study and comparison of documents.

The sub-committee notes further that the mathematical discussion of the properties of these prisms, investigated by Prof. Geo. H. Hallett, of the University of Pennsylvania, shows that their selection and application are based on correct scientific principles, and this fact, therefore, increases the evidential value of the information obtained by their proper use in the hands of an experienced observer.

The investigators recommend the award of the John Scott Legacy Premium and Medal to applicant for his contributions to the science of bibliotics. (*Sub-Committee*, Joseph W. Richards, Chairman; Jos. H. Hart, Samuel P. Sadtler, C. C. Heyl.)

(No. 2331.) *Electric Protective Devices.* The Intern'l Burglar Immunity Co., Philadelphia.

ABSTRACT: The system of applicant is protected by letters-patent of the United States, numbered 725,900, 730,422 and 735,324, and dated respectively April 21, June 9, and August 4, 1903.

It is designed for the protection of bank vaults, safes, and isolated places in general, and depends essentially upon the use of several circuits and the employment of relays in these circuits, which, by their becoming active or inactive, as the case may be, bring the alarm system into action.

The main claims of superiority over the existing systems are based upon the use of a separate current, whereby the system derives part of its protective qualities from the place protected, instead of from a central station. The system is further protected by current derived from an outside source; for instance, an electric lighting circuit, the tampering with which at any time causes an alarm.

The report finds the system to be well designed, and well adapted for the purpose for which it is chiefly intended, namely, the protection of isolated places. A Certificate of Merit is awarded. (*Sub-Committee*, Richard Gilpin, Chairman; Geo. P. Scholl.)

(No. 2281.) *The Art of Reducing the Attenuation of Electrical Waves and Apparatus.* Michael O. Pupin, New York.

Previously reported, and made the subject of a protest from Mr. C. J. Reed. The Sub-Committee suggested some minor amendments in its report, in consideration of Mr. Reed's criticisms, and re-ffirmed its previous conclusions. As amended, the report was adopted. The Elliott Cresson Medal is awarded to applicant. (*Sub-Committee*, C. C. Heyl, Chairman; E. A. Scott.)

The following reports passed first reading:

(No. 2340.) *Method of Color Photography.* Michael and Henry M. Miley, Lexington, Va.

(No. 2352.) *Phonosphere.* The Phonosphere Co., New York.

(No. 2358.) *Automatic Pistols.* The Colt's Patent Firearms Mfg. Co., Hartford, Conn.

(No. 2360.) *Method of Making Replicas of Diffraction Gratings.* Frederic E. Ives, New York.

WM. H. WAHL,
Secretary.

JOURNAL
OF THE
FRANKLIN INSTITUTE

ERRATUM: *Art.* BORSCH. A SOLID INVISIBLE BIFOCAL LENS. *Journal*, April, 1905, page 322. Third line from end of article after "any further grinding" interpolate

"Owing to the time already occupied, and which I think has been too much for so dry a subject as lenses, I will dispense with reading the formula for making the different foci required, which is only of interest to that extremely limited number of specialists who make optical glass, and will close my paper and . . . .

such apparatus. It is not often that the considerations on one side so strongly outweigh those on the other as is the case with the steam turbine.

The advantages claimed for steam turbines are many and the statement of a few of them may be of interest.

One generally considers the question of the steam economy of the turbine as compared with that of a steam engine as one of great importance. As much of the available data is difficult to compare, its discussion will be taken up later.

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